

TECHNICAL REPORT No. 3



MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES

MINES AND GEOLOGICAL DEPARTMENT

**GEOLOGY AND
GROUND WATER CONDITIONS
IN THE
NAKURU AREA**

by

**G.J.H. McCall, B.Sc., Ph.D., A.R.C.S., D.I.C.
Geologist**

**First print 1957
Reprint 2007**

**GEOLOGY AND
GROUNDWATER CONDITIONS
IN THE
NAKURU AREA**

By

**G. J. H. McCALL, B.Sc., Ph.D., A.R.C.S., D.I.C.
Geologist**

FOREWORD

This report on the geology and groundwater conditions in the Nakuru/Elmenteita region of the Rift Valley is the first of a series, which, in time, will cover the more important agricultural areas of Kenya. Although this report makes use of all the records of drilling operations to date, this has been supplemented by a considerable amount of field work. Much of the new work done is geological, but it has long been realized that the problems of groundwater cannot be understood without detailed geological mapping and an assessment of the structural geology of the region.

The conclusions reached in this report are by no means complete. Two important questions remain to be answered:—

- (i) How much of the annual rainfall passes the capillary zone of the ground to become available as groundwater? (*X*.)
- (ii) How much groundwater is lost by evaporation or escapes from the groundwater bodies into areas of less economic significance or to uneconomic depths? (*Y*.)

In our present state of knowledge answers cannot be given to these questions. However, the difference (*X*—*Y*) represents the maximum amount of groundwater available for development, and is thus still indeterminate.

The present study indicates that there is probably a subterranean watershed at the southern boundary of the area and there is little possibility of appreciable escape from the east or west flanks. The subterranean escape of water to the north is possible, but its extent cannot yet be assessed. It can, however, be said that the development of the groundwater resources in the area can safely proceed without any immediate risk of overwithdrawal.

As development progresses and more water is drawn from the groundwater reservoir, the rest level of the water-table is likely to fall. A state of equilibrium may be presumed at the present time, where the groundwater not being used, now escapes in spring flows, by evaporation from the lakes or by subterranean flow. To enable more groundwater to be used, there must be a readjustment of the water-table, small though this may be, to decrease losses. The use of more groundwater may, for example, lower the present lake levels. There could, however, come a stage when, without increasing the utilization of groundwater, the water-table continues to recede. This is the danger point, for then the groundwater body is being drawn upon in excess of recharge, and disaster is not far away.

The effects of the future development of the groundwater resources of this area must be kept under observation and a halt called before a harmful recession of the groundwater table commences. This situation is not likely to occur for some considerable time at the present rate of development.

The author, at the time this work was undertaken, was a geologist working with the Groundwater Section of the Hydraulic Branch of the Public Works Department, under the Senior Geologist, Mr. S. Stock, A.R.S.M. Facilities provided by the Department of Mines and Geology for some of the more detailed petrographical studies are acknowledged.

Nairobi,
2nd May, 1957.

H. J. SQUIRES,
Chief Hydraulic Engineer.

CONTENTS

	PAGE
I INTRODUCTION	1
II HUMAN SETTLEMENT AND AGRICULTURAL DEVELOPMENT	2
III GENERAL SUMMARY OF THE GEOLOGICAL HISTORY OF THE RIFT VALLEY IN THE NAKURU AREA	3
IV GEOLOGICAL FORMATIONS—VOLCANIC ROCKS	5
V THE MENENGAI VOLCANO	12
VI THE EBURRU AND ELMENTEITA VOLCANIC SERIES	21
VII THE SEDIMENTS	24
VIII TECTONICS	28
IX HYDROLOGY	30
X HISTORY AND RESULTS OF GROUNDWATER DEVELOPMENT	34
XI DESCRIPTION OF AQUIFERS	35
XII GROUNDWATER CONDITIONS	37
XIII GEOPHYSICAL METHODS OF PROSPECTING FOR WATER	40
XIV SODA DUST FROM LAKE NAKURU	41
XV THE NJORO RIVER	42
XVI THE POSSIBILITY OF UTILIZING STEAM AS A SOURCE OF POWER IN THE RIFT VALLEY	43
APPENDIX—ANALYSIS OF DRILLING RESULTS	45

NOTE.—Full details of all boreholes drilled in the area covered by this report appear at the end of the Appendix.

ILLUSTRATIONS

	PAGE
Fig. 1.—Map and Serial Sections of a small fault block, 1½ miles west of Kariandusi. (After B. N. Temperley)	11
Fig. 2.—Subsidence Calderas. The Mechanism of Formation. (After A. Holmes, van Bemmelen and H. Williams.)	15
Fig. 3.—Menengai Crater. View from the western rim	17
Fig. 4.—(a) Sketch of Subsidence Structure on western side of Caldera.	18
(b) Sketch showing the reversal of the normal outward slope of lava flows in a promontory projecting from the western wall of Menengai Caldera, consequent on the foundering of the central part of the volcano	18
Fig. 5.—Sketch showing the renewed faulting of basaltic tuffs of "High" volcano	25
Fig. 6.—Sequence of changes of the Rift Valley lakes. (After E. Nilsson)	26
Fig. 7.—As above	27
Fig. 8.—Isohyets of average rainfall for the 10 year period 1943–1952	31
Fig. 9.—Diagrammatic representation of the hydrological cycle in the Rift Valley	33
Fig. 10.—Comparison of a confined aquifer producing artesian conditions and the open system of aquifers typical of the floor of the Rift Valley	38
Fig. 11.—Comparison of resistivity curves in boreholes drilled in the Nakuru Area	41
Plate 1.—Mould of tree (completely vaporised) preserved in welded tuff flow, Nakuru Municipality Quarry, Ravine Road	12

MAPS

1. Geological map of Nakuru Area.
2. Map showing groundwater conditions in the Nakuru Area.
3. Geological Sketch Map of the Menengai Caldera.
4. Geological Sketch Map of the basaltic cones of Elmenteita.

SECTIONS

Geological Sections illustrating groundwater conditions in the Nakuru Area.

ABSTRACT

An area of approximately 1,200 square miles in the Rift Valley near Nakuru has been studied in detail in order to gain more information about groundwater conditions. The geology of the area, so far but briefly referred to by J. W. Gregory, has been described in some detail. The nature of the aquifers and the hydrostatic conditions have been described, and the effect on groundwater conditions of the Menengai and Elmenteita volcanoes, still active to a very minor degree, has been assessed. The failure of boreholes in the Kampi-ya-Moto area is explained, and the presence of groundwater ridges and perched water-tables under influent steams has been described.

The geology and groundwater conditions have been illustrated by maps and sections. A hydrological cycle in the internal drainage system of the Rift Valley has been suggested.

Detailed geological maps have been drawn of the Menengai and Elmenteita volcanic centres, both the source of lava eruptions within the last few hundred years.

Geophysical methods of prediction have been discussed, and are considered to be of little value in the prevailing geological conditions. Brief notes on the groundwater conditions in the Lake Nakuru basin and their bearing on the soda dust problem, and the possibilities of natural steam as a source of power in the Rift Valley are included.

GEOLOGY AND GROUNDWATER CONDITIONS IN THE NAKURU AREA

By G. J. H. McCall, Ph.D.

CHAPTER I—INTRODUCTION

This report covers the geology and the groundwater conditions in an area of the Rift Valley near Nakuru lying just south of the Equator and intersected by the 36° E. meridian.

The field survey was carried out in 1952–53 as part of a detailed investigation of the geological and groundwater conditions in the northern part of the settled area within the Rift Valley. The area was chosen for the following reasons:—

- (i) It is an area in which geophysical methods of prediction have proved to be of little value.
- (ii) The extent and geological relationships of thermal conditions in this part of the Rift Valley, particularly those of the recent volcanic centre of Menengai, required investigation.
- (iii) An extensive area near Kampi-ya-Moto had failed to produce a single successful borehole, the reasons for which were obscure.

The limits of the area are: the Mau Escarpment to the west; the Eburru Volcano to the south; and the Kamasia Reserve to the north. The eastern limit was taken along the line of the Subukia–Bahati Forest Escarpment and its southerly extension in the Gilgil Escarpment. A part of the Njoro area has also been included. For convenience the area has been divided into six sub-sections:—

- (1) Nakuru.
- (2) Rongai.
- (3) Solai–North Menengai.
- (4) Kampi-ya-Moto–Lomolo.
- (5) Elmenteita.
- (6) Njoro (North).

The geological survey was carried out by means of detailed mapping of surface exposures, together with microscopic examination of all available samples from completed boreholes. As more than 150 boreholes have been drilled ample data is available for such a study of groundwater conditions in the extensively faulted Tertiary volcanic rocks.

Topographical detail was obtained from air photographs, military 1:25,000 maps and preliminary plots issued by the Survey Department of Kenya.

Altitudes of boreholes were tied in to known heights by means of aneroid measurements, but owing to the large diurnal variation no very high degree of accuracy is claimed for these measurements. The accuracy is sufficient, however, to provide a picture of the subsurface hydrostatic conditions throughout the area. Many of the boreholes in the vicinity of Nakuru town have subsequently been accurately surveyed by the Hydrology Section and these results are incorporated in this report.

This is the first area in which a detailed groundwater survey has been completed, but similar investigations are being carried out in other areas of the Colony.

References to the area in earlier geological literature are to be found in the following publications:—

The Geology of the Rift Valley of East Africa, J. W. Gregory, 1921.

The Underground Water Resources of Kenya Colony, H. L. Sikes, 1934.

The Stone Age Cultures of Kenya, L. S. B. Leakey, 1931 (with geological summary in appendix by J. D. Solomon).

Quaternary Glaciations, and Pluvial Lakes in East Africa, E. Nilsson, 1932.

An Outline of the Geology of Kenya, S. M. Cole, 1950.

East African Lakes, L. S. B. Leakey, 1932.

This report was revised in March, 1957, certain amendments being made in the light of new data obtained from further boring for water and geological investigations carried out near Gilgil by Dr. B. N. Temperley.

CHAPTER II—HUMAN SETTLEMENT AND AGRICULTURAL DEVELOPMENT

With the exception of the Kamasia Native Reserve to the north and large areas of forest on the Mau and Bahati Escarpments, the Nakuru area is almost entirely alienated for European settlement. Farming is the mainstay of the area. Mixed farming predominates in the richer and more fertile districts of Solai and Rongai, while larger ranching farms occupy the dry, grassy plains in the vicinity of Lake Nakuru and Elmenteita. Wheat and maize are the main cereal crops grown while coffee flourishes in the Solai Valley. Lucerne for feeding cattle is grown by irrigation from surface streams and boreholes. Sisal plantations occupy a large tract of dry country on the edge of the Kamasia Reserve near Kampi-ya-Moto, Lower Molo and Ol Punyata, and another 8,000-acre plantation is situated on the west side of Lake Nakuru.

Nakuru is the centre of this large farming area, having as yet few industries other than those related to the farming operations in the district (e.g. tanning, wool treating, etc.). It is a flourishing and rapidly expanding commercial centre, and the administrative centre of the Rift Valley Province.

The main demand for water comes from the farming community. The rainfall over the area is not heavy and is liable to fail over successive years. The soil over much of the area is too porous to allow the storing of water in small surface reservoirs. Certain parts of the area are well watered by surface streams, and in these localities there has been little recourse to groundwater resources. Amongst such areas are the valleys of the Molo and Rongai Rivers and the Bahati Plain. However, small stream flows combined with stream losses have brought forward proposals for the piping of water from these streams to the farms in order to increase the amount of water available for development. Schemes are in being from the Crater Stream and the Njoro River. A large scheme has recently been completed from the Rongai River, the flow of which has been augmented by a tunnel driven a mile into the hills above Elburgon. Further pipe-line schemes are being constructed on the Westacre, Vissoi and Olobanaita Rivers.

Unfortunately these schemes, although important, cannot relieve the water shortage in such areas where deep boring has so far been a complete failure. One of the objects of this report is to explore the possibility of extending the areas which can be supplied from groundwater reserves. Of the 146 boreholes completed in this area at the time the field work for this report was carried out, 118 were for the purpose of farm development. Although the first rush of post-war development has passed, the demand for the further development of groundwater resources will continue for many years to come, especially in those areas where groundwater is the only practical source of increased water supplies.

Twenty-eight boreholes have been drilled for purposes other than the development of the farming industry. These include such purposes as municipal supply, Nakuru industries (wool treatment, tanning, etc.), cooling water for electricity power supply, saw-mills, residential plots and road constructions. The Nakuru municipal water supply uses both river and borehole waters. The fluorine content of the groundwater alone is considered to be too high for a public water supply. Very little close drilling has been carried out except in the Mereroni area near the municipal boundary of Nakuru. The boreholes in this locality have high yields and are used by the Municipality of Nakuru. Although there is a danger of overpumping in this locality it has not yet taken place.

CHAPTER III—GENERAL SUMMARY OF THE GEOLOGICAL HISTORY OF THE RIFT VALLEY IN THE NAKURU AREA

The area surveyed lies within the main Rift Valley of Kenya, known to geologists as the Gregory Rift Valley. This structure, which is part of the greater Rift System extending from Syria to the Zambesi, is a complex fault trough with a general north-south orientation. The rift valleys do not form unbroken north-south troughs, the system being broken up by oblique structures and shorter fault troughs normal to the main trend, of which the Gulf of Aden and the Kavirondo Rift Valley are among the best examples. These lateral and oblique structures are in most cases associated with a lateral offset of the main Rift Valley. They have been discussed by R. B. McConnell [4] who attributed them to earlier shear zones in the Basement platform, caused by a shearing couple resultant on ancient orogenic movements of great magnitude. McConnell considers that the Tertiary structures utilized the same lines of weakness, although resultant on a much later orogenic adjustment of the earth's crust.

Nakuru is situated at the intersection of the Kavirondo Rift Valley, a fault trough extending westwards to the shores of Lake Victoria, with the Gregory Rift Valley. At this junction the Rift Valley is complicated by two factors. Firstly, a definite deflection in its course can be observed resulting in more complex fault structures than are normally seen in the straighter sections of its course. Secondly, as in the case of the "Mbeya Angle" in Tanganyika and other intersections, the junction has been the focus of intense vulcanism, evidenced by four major volcanoes—Loldiani, Kilombe, Menengai and Eburru. Loldiani stands astride the junction of the two Rift Valleys, while Menengai and Kilombe lie to the east, rising from the floor of the main Rift Valley. Eburru, a twin-peaked massif, is situated slightly to the south, forming a barrier across the Rift Valley floor. Later eruptions have been on a smaller scale and mainly confined to renewed activity in the earlier centres. However, a later group of volcanoes developed along a zone of intense north-south faulting extending from Lake Elmenteita over the eastern shoulder of Eburru to the west shore of Lake Naivasha. Basaltic tuff and cinder cones have arisen, and basalt lava flows have been poured out in successive eruptions extending to comparatively recent times.

The Tertiary history of the Rift Valley commenced with downwarping of narrow troughs on the site of the present-day rift valleys. This downwarping interrupted the drainage of that part of the African Shield, and a series of shallow lakes were formed;

the deposits formed in these lakes are the Miocene Lake Beds of Rusinga Island, Tambach and Turkana, which rest upon a peneplained surface of ancient metamorphic rocks. Among the earliest lavas to be poured out were the plateau lavas, phonolite flows extending over vast areas of peneplained Basement Complex, and the first Tertiary nephelinite volcanoes. These are the Laikipia and Uasin Gishu phonolites which directly overlie the Basement Complex and Miocene Lake Beds, on the eastern (Elgeyo) escarpment of the Rift Valley to the north of Nakuru.

The plateau phonolites have no visible source of origin, but their extent and uniformity of composition leads to the conclusion that they were erupted from fissures which opened during the earliest tensional phase of the rifting. Plateau phonolites must cover great areas of the down-faulted peneplained surface of the ancient Basement rocks in the Rift Valley, but in the Nakuru area no comparable types are seen and it is presumed that they have been completely obscured by later effusions of lava and pyroclastic deposits. Near Lake Hannington, however (to the north of Solai), the Losuguta phonolites, which closely resemble the plateau phonolites, emerge in a great north-west-facing scarp, a feature supporting this assumption.

The eruptions from fissure sources appear to have continued for a considerable geological period on the Rift floor after the first great fault displacements occurred. The oldest volcanic rocks exposed on the valley floor in the Nakuru area are phonolites, basalts and phonolitic trachytes, extensive in outcrop and uniform in composition, having no central sources visible at the present day. It is thought that movements along faults were closely associated with a welling out of lava from fissures along the margins and across the floor of the Rift. These flows are strongly faulted and form the clear-cut scarps and grid structures. It is, however, the opinion of the writer that these are not among the earliest fault structures; a view that is borne out by the fact that these faults do not exactly coincide in direction with the main marginal scarps of the Mau, and the Bahati-Subukia Horst, an outlying spur of the eastern wall which both from the tectonic viewpoint and from the nature of its component rocks is considered to be part of the eastern wall of the Rift Valley.

After the faulting had diminished in magnitude the great trachyte volcanoes arose. These are not affected by major faults though slight subsidences along earlier lines of weakness have occurred. Loldiani and Eburru have no well-preserved craters, and their slopes are appreciably dissected by erosion. Kilombe is equally dissected, but appears to possess a comparatively well-marked, though eroded, crater. Menengai has dissected slopes, deep gullies cutting into the loose pyroclastic mantle. The present-day appearance of Menengai differs from the other three in that it is the only one of the volcanoes that has been affected by cauldron subsidence. No detailed description of these volcanoes (other than Menengai) is given in this report, being beyond the scope of this survey.

The later central eruptions are characterized by tongue-like lava flows of restricted extent, the source and the termination of these flows being easily determined when mapping in the field. Renewed vulcanism has occurred in Menengai, extending up to the last few hundred years, and this may also be true of some of the other volcanoes. Subsequent to the great volcanoes being built up eruptions were much more limited in extent—and only the small volcanic cones of Elmenteita and Honey-moon Hill arose. These do not exceed a mile in diameter, and many a smaller. The largest, named High, stands about 500 feet above the surrounding country, but the majority do not stand up more than two to three hundred feet. The outer slopes, composed of compacted tuff, are not appreciably gullied, but the cones have been affected by minor faulting. Present-day volcanic activity is limited to minor steam vents in the volcanic zones of Menengai and Elmenteita.

The tectonic history and allied vulcanism comprises only part of the picture, for, concurrently sedimentation took place. Since the time when the first Miocene warp movements interrupted the drainage pattern of the African shield, the Rift Valley has been an area of internal drainage. Successions of shallow lakes formed only to be deformed by earth movements, broken up by faulting and dammed up by lava flows. Into these ephemeral lakes volcanic detritus was carried by short and intermittent streams flowing off the higher ground. Thus the volcanic rocks of the Rift Valley are intercalated with sediments—volcanic grits, clays and reworked tuffs. In the Pleistocene era a great lake extended over the Gilgil Escarpment from Menengai to Lake Naivasha and since that time a series of separate lakes have occupied its site, diminishing gradually to the present shallow lakes of Naivasha, Nakuru and Elmenteita.

The continuation of earth movement in the Rift Valley up to the present day is well demonstrated in Nilsson's [5] work on the Pleistocene glaciations of East Africa. Earthquakes and fissuring of the land surface have occurred during the last 30 years and the Nakuru area must still be considered as a zone of crustal instability, though of minor order compared with the world's great earthquake zones.

CHAPTER IV—GEOLOGICAL FORMATIONS—VOLCANIC ROCKS

The volcanic rocks exposed in the Mau and Bahati-Subukia Escarpments, and those of the Legislian Escarpment are thought to be the oldest volcanic rocks exposed within the area. The succession is as follows:—

(a) *The Older-faulted Volcanic Rocks*

(3) Mau and Bahati tuffs.

(2) Solai Phonolite.

(1) Solai Basalt.

Reconnaissance of the Mau has revealed that the bulk, if not all, of the volcanic rocks near the surface consist of a series of greenish-grey welded trachytic tuffs, together with yellow pumic tuffs, and sedimentary intercalations, reworked tuffs and clay. On the Bahati Escarpment between Mbaruk and Gilgil similar welded trachytic tuffs and yellow pumice tuff intercalations are the only formations exposed; while to the north of Mbaruk and at Solai they overlie black porphyritic phonolites. To the north of Milton's Siding the welded tuffs disappear altogether and extensive flows of the porphyritic phonolites form the surface of the fault blocks.

The phonolites underlying the Mau and Bahati tuff formation have been named "Solai Phonolite". They consist of a series of flows characterized by abundant idiomorphic nepheline phenocrysts easily identifiable in thin section, and often to the naked eye. The phonolite exposed on the Subukia escarpment is black, massive and characterized by prominent tabular felspar phenocrysts. Numerous major faults are exposed along the escarpment and in the vicinity of these dislocations the phonolite is either smashed or altered to a dove-grey to white closely jointed alteration product, with the tabular felspar phenocrysts still preserved.

The Legislian Escarpment is capped by a thin layer of welded trachytic tuff dying out to the north and underlain by a succession of phonolite flows. These include porphyritic phonolite similar to the phonolite of the Subukia Escarpment, and finer textured varieties devoid of felspar phenocrysts. Locally, streaky textures are developed. A characteristic type of phonolite exposed on this escarpment shows abundant phenocrysts of nepheline surrounded by a ring of green aegirine augite, felspar phenocrysts being sparse or absent.

The fault blocks in the valley between the two escarpments are composed of black phonolite with tabular felspar phenocrysts matching the phonolite of the Subukia Escarpment; to the south a solitary fault scarp of the same phonolite is exposed on Mascall's farm. To the west of the Legisianan Escarpment black phonolites outcrop as far west as Lomolo; these are frequently fissile and rarely porphyritic; the phonolite surface is, however, overlain by patches of welded trachytic tuff, and there can be little doubt that they are part of the same series of phonolitic flows which outcrop on the Legisianan Escarpment. The relation of the welded tuff to the phonolite (brought out in the mapping) suggests that the phonolite may have been already down-warped or faulted at the time at which the welded tuffs were deposited. For in the Solai and Subukia areas the welded tuff dies out rapidly as one passes away from the line of the now hidden older fault, and phonolite is laid bare on the surface. The welded tuff has thus apparently been banked against an existing escarpment. Preliminary reconnaissances of the Mau Escarpment near Elburgon and Londiani suggest that here also the very deep welded tuff formation thins out and disappears as soon as the crest of the Mau is traversed.

Streaky phonolites form the long fault block which lies east of McKenzie's farm. These resemble those of the Legisianan Escarpment. They were first mapped as phonolitic trachyte, but it is clear from structural considerations, and their relation to the welded tuffs, that the fault block must be made up of older rocks of the Solai Phonolite group, though there are probably a few small outliers of phonolitic trachyte of the later Nakuru group lying unconformably on the phonolite at the south end, near to the line of the older fault, which here follows the line of the Nakuru-Ol Punyata road.

The basalt underlying the Solai Phonolite is exposed on the crest of the road pass from Milton's Sidings to Subukia. The succession in the road cutting is:—

(2) Green massive phonolite.

(1) Buff basaltic ash.

Aphanitic basalt; dove-grey in colour, with elongated vesicles infilled with yellow and white secondary deposits.

This basalt underlying the Solai Phonolite has been named "Solai Basalt". Basalts are shown below the Solai Phonolite in sections of boreholes C1746, C1745 and C1954. These were easily recognisable, but many of the lava specimens examined from the vicinity of the Subukia Escarpment showed extreme alteration and decomposition, and the identification is only tentative. It is possible that there are more intercalations of basaltic lava than are shown.

A fresh black basalt was noted forming a thin layer within the phonolite on the road pass between Milton's Sidings and Subukia. This has not been shown on the map. From the contrast between the fresh state of this lava and the enclosing phonolite it is considered to be a small dyke of much later age, probably contemporary with the Elmenteita fissure eruptions. This occurrence shows that small thicknesses of basalt may be found in any borehole sample in this locality, quite unrelated to the generally regular stratigraphic succession of lava flows.

A phonolite in every way similar to the Solai Phonolite outcrops on the Bahati Escarpment to the north of Mbaruk; it underlies yellow pumice tuff and welded trachytic tuff.

A summary of the successions of these oldest volcanic rocks in the various localities is given in Table I.

TABLE I.—SUCCESSION IN THE OLDEST VOLCANIC ROCKS IN NAKURU AREA

	Mau Escarpment	Mbaruk	Subukia Escarpment	Legislanan Escarpment	Borehole C.1954	Borehole C.1765	Borehole C.1746	Borehole C.1834
Mau and Bahati Tuffs	Welded Trachytic Tuff	Welded Trachytic Tuff	Welded Trachytic Tuff	Welded Trachytic Tuff	Welded Trachytic Tuff	—	Welded Trachytic Tuff	Welded Trachytic Tuff
	*(Yellow Pumice Tuff)	*(Yellow Pumice Tuff)	*(Yellow Pumice Tuff)					
	*(Reworked Tuff Clay)							
Solai Phonolite		Porphyritic Phonolite	Porphyritic Phonolite	Phonolite (extensive series of flows, predominantly porphyritic)	Phonolite	Phonolite	Phonolite	Phonolite
Solai Basalt			Basalt		Olivine Basalt (Phonolite)	Basalt	Basalt	Basalt

*Intercalations.

TABLE II.—SUCCESSION IN LATE VOLCANIC ROCKS OF THE RIFT VALLEY FLOOR

NAKURU PHONOLITIC TRACHYTE

Lake Nakuru (West Side)	Lake Nakuru (East Side, Sirkon)	Elmenteita (Soysambu)	Elmenteita (Cole's Farm Gilgil)	Bahati Escarpment Mbaruk	Bahati Escarpment
Phonolitic Trachyte. Black to greenish-grey fissile, streaky texture, aphanitic; nepheline occasionally identifiable Sparse prismatic felspar boulders of Mbaruk Basalt.)	Phonolitic Trachyte. Black to greenish-grey, fissile, streaky texture glassy bands common. Locally finely scoria- cious. Nepheline occasionally identifi- able. Sparse prismatic felspar phenocrysts. (Included boulders of Mbaruk Basalt.)	Phonolitic Trachyte.* Light grey, aphanitic; upper surface of flow vesicular, weathering in characteristic honeycomb structure. Nepheline not identi- fied. Sparse prismatic felspar phenocrysts.	Phonolitic Trachyte.* Grey to light green, vesicular upper surface weathering in honeycomb structure. Felspar phenocrysts yellow, clear and prismatic in form, size small, but more abundant than else- where.	—	(South east of Nakuru— Thomson's Falls Road.) Phonolitic Trachyte. Greenish-grey, fissile aphanitic; vesicular upper surface showing characteristic honey- comb weathering. Sparse prismatic felspar phenocryst. Nepheline not identified.
Basalt. Grey, prominent plagioclase phenocrysts; fine, usually partially glassy groundmass.	—	MBARUK Basalt. Grey, prom- inent plagioclase phenocrysts; fine, usually partially glassy groundmass.	BASALT —	Basalt. Grey, very fresh, prominent plagioclase pheno- crysts; fine, usually partially glassy groundmass.	Basalt. Grey to black prominent plagioclase phenocrysts; fine usually partially glassy groundmass.

*Or quartz trachyte.

The Solai succession has been barely outlined, and a fuller understanding will only be obtained when the area between Subukia and the Sattima (Aberdare) massif has been surveyed.

(b) *The Younger-faulted Volcanic Rocks*

To the south of Menengai a series of lava-flows outcrop in faulted blocks, emerging from thick Pleistocene deposits of the Lake Nakuru-Elmenteita Basin. These lava flows are considered to be of a much later age than the formations described above and are named "Nakuru Phonolitic Trachyte"* and "Mbaruk Basalt".

The successions observed in the main localities in which these lavas outcrop are summarized in Table II.

The Mbaruk Basalt is the most easily identified lava in the area, being characterized by plagioclase phenocrysts up to a centimetre in length, a most unusual feature in Tertiary basaltic lavas of the Rift Valley. It is similar in appearance and petrography to the Kijabe Basalt described by Shand [11 and 12] and Shackleton [14], but lacks the pronounced alignment of phenocrysts of that basalt. It is clearly a flow later than the main boundary faults of the Rift Valley, and correlation with the Kijabe Basalt is improbable in spite of petrographic similarity.

On the west side of Lake Nakuru and at Soysambu an old land surface separates the basalt from the overlying phonolitic trachyte. In the first locality, a few feet of brick-red material and a thin layer of buff-stratified volcanic sediments separates the two lavas; at Soysambu the old land surface is less well marked. The two lava formations appear to be almost entirely concordant, little erosion and no tectonic disturbance having taken place between the extrusion of the basalt and the phonolitic trachyte.

Evidence from borehole samples (C869) suggests that the Mbaruk Basalt is underlain by a porphyritic phonolite. A dark lava of such composition appears to underlie the basalt about two miles north of Mbaruk. Exposures are, however, poor in this locality, and owing to the situation of the outcrop on a major fault zone, it is not possible to say definitely whether the relationships are normal. At the Nakuru Lake Syndicate quarry a cliff of massive black lava is being worked for road stone; this lava apparently underlies the Mbaruk Basalt. It has the appearance of a phonolite, but the texture is too fine for its composition to be determined without analysis.

The phonolitic trachytes are extensively developed on the west side of Lake Nakuru and on the east side (Sirkon). In both localities there appear to be several flows piled on top of one another. At Soysambu and to the north of Mbaruk there is only one flow of trachytic lava overlying the Mbaruk Basalt; in many localities its thickness does not exceed to 30 feet. Near Mbaruk Station the phonolitic trachyte is absent altogether.

To the east of Lake Elmenteita the phonolitic trachyte has a much greater development, and the fault scarps of the Gilgil series are composed of a single flow locally more than 200 feet thick. The origin of these flows is not known. They do not appear to emanate from any central volcano that can be recognized at the present day. Their extent and uniformity over a wide area, particularly striking in the case of the Mbaruk Basalt which has been identified over an area of about 130 square miles suggests that eruption from fissures by a process of quiet welling out during

* The Nakuru Phonolitic Trachyte was given this name on account of the frequent discovery of nepheline in sections from the western half of the area. At the time of revision (March, 1957) examination of the lavas of this group from near Gilgil showed them to be mainly quartz trachyte (verbal communication, B. N. Temperley). Comendites have also been collected from the fault blocks near Elmenteita. The conclusion is inescapable that there is a wide composition range, possibly even within single flows and the name Nakuru Trachyte Group is suggested as a preferable alternative.

a period of tension is the most likely mode of origin. This is supported by the fact that there are no pyroclastics other than insignificant wisps of welded tuff associated with these lavas.

The relationship of these lavas to the tuffs which are exposed on the Mau and Bahati Escarpments was not easily determined. From a careful examination of the Bahati Escarpment between the Nakuru to Thomson's Falls road-Mbaruk-Kariandusi and Gilgil the following facts were discovered during the original geological survey in 1952-53:—

- (i) On the escarpment north of Mbaruk there is a marked structural discordance between the tuffs forming the upper part of the escarpment and the Mbaruk Basalt which outcrops in a steep fault scarp along the foot. The tuffs form a comparatively gentle, strongly dissected slope, and outcrop in a series of fault blocks tilted strongly towards the south. The Mbaruk Basalt forms a continuous scarp between Mbaruk and the Nakuru-Thomson's Falls road, apparently unaffected by the tilting seen in the tuff above it and to the east.
- (ii) No exposures of Mbaruk Basalt or Nakuru Phonolitic Trachyte are seen to the east on the high ground of Bahati; nor are they seen in the high ground of the Mau.
- (iii) The Bahati Tuff and the Nakuru Phonolitic Trachyte are seen in contact a mile west of Kariandusi diatomite quarry. They are separated by an unconformity. The margin of the tuffs of the Bahati Escarpment makes a continuous line running south from the Nakuru-Thomson's Falls road to Gilgil. It is repeatedly offset by north-south fault dislocations.
- (iv) An outcrop of phonolite, similar in appearance and texture to the Solai Phonolite, emerges from beneath the yellow pumice tuffs and welded tuffs that form the hill called Ngorika, three miles north of Mbaruk. This phonolite separates the yellow pumice tuff from the Mbaruk Basalt. Further south the two formations are in contact, and to the north phonolitic trachyte is interposed between the tuffs forming the upper part of the escarpment and the Mbaruk Basalt.

The only satisfactory explanation for these very confused relationships is that the Bahati scarp of the Rift Valley was already formed when the Mbaruk Basalt was extruded. The tuff formations and Solai Phonolite exposed in the fault scarps were derived from much earlier eruptions. These fault scarps were strongly eroded, and all trace of the original boundary faults of the Rift Valley has been obscured, but the rounded escarpments of the Mau and Bahati remain, representing the original marginal scarps of the Rift Valley.

The Mbaruk Basalt and the Nakuru Phonolitic Trachyte are envisaged as having been erupted from fissures during a subsequent renewal of tension. They were restricted in extent to the floor of the earlier valley which they covered in flat sheets of lava. Subsequently large-scale faulting disrupted these flat sheets into fault blocks, at the same time forming the secondary steep set of fault scarps at the foot of the Bahati Escarpment, north of Mbaruk and at the foot of the Mau on the west side of Lake Nakuru.

In 1957 Dr. B. N. Temperley re-examined exposures on and to the west of the Gilgil Escarpment. His conclusions were in agreement with the field relations described by the writer, and he was able to locate the unconformity between the Nakuru trachyte and the welded tuff and tuff formation of the Bahati Escarpment. He interprets the slivers of later lava up to a few hundred yards thick seen throughout the length of the Bahati Escarpment at the foot of the slope of older rocks as due to re-faulting—along the original boundary fracture of the rift graben, after erosion had cut back the

fault scarp some hundred or so yards from the line of the fault and later trachyte had flowed over it and up against the eroded scarp. The actual unconformable contact can be seen in the fault block one and a half miles west of Kariandusi diatomite quarry (see Fig. 1 drawn by Dr. Temperley) and possible on the Gilgil Escarpment, where it is nearly vertical and might be a fault contact, though there is no evidence in the topography of any displacement.

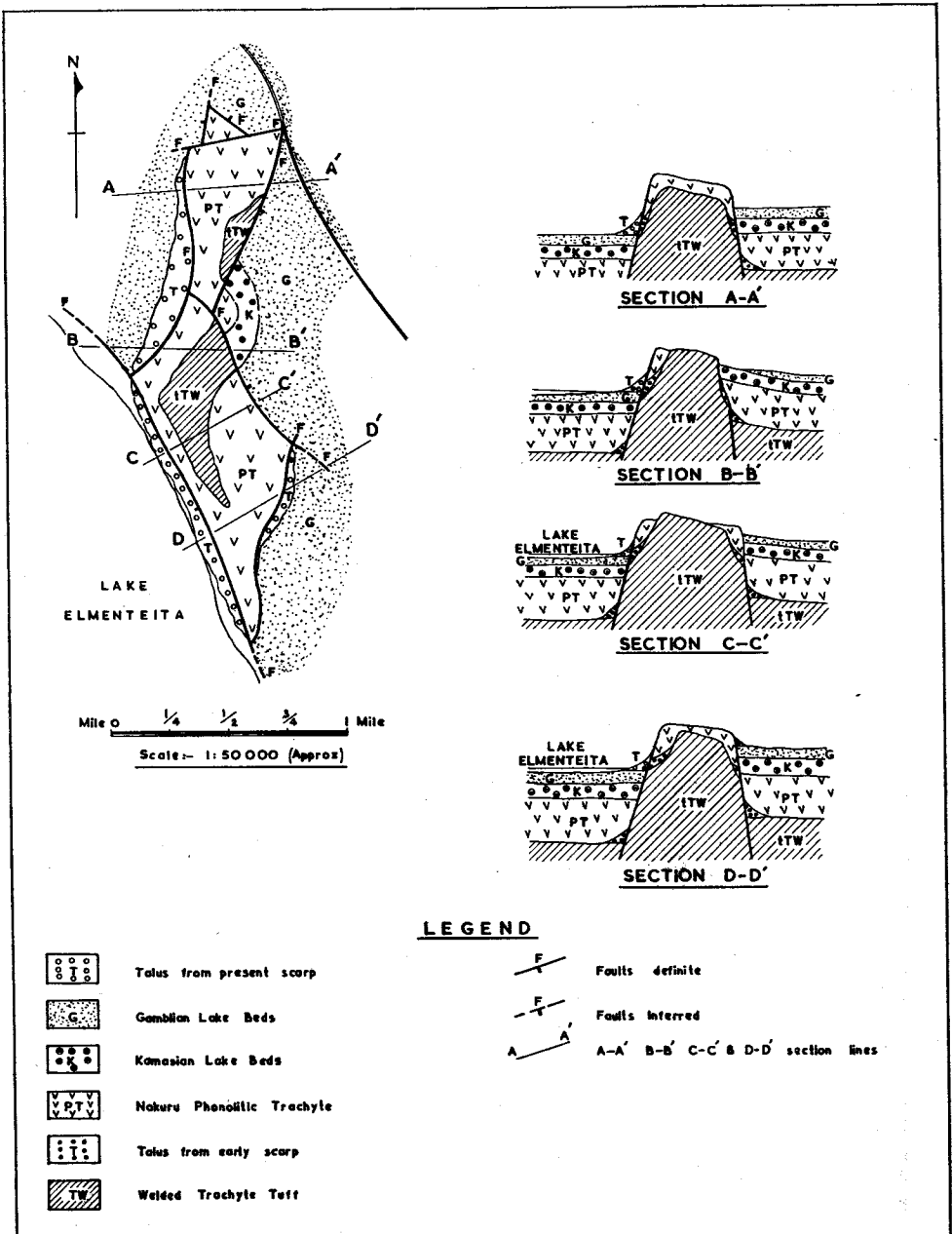
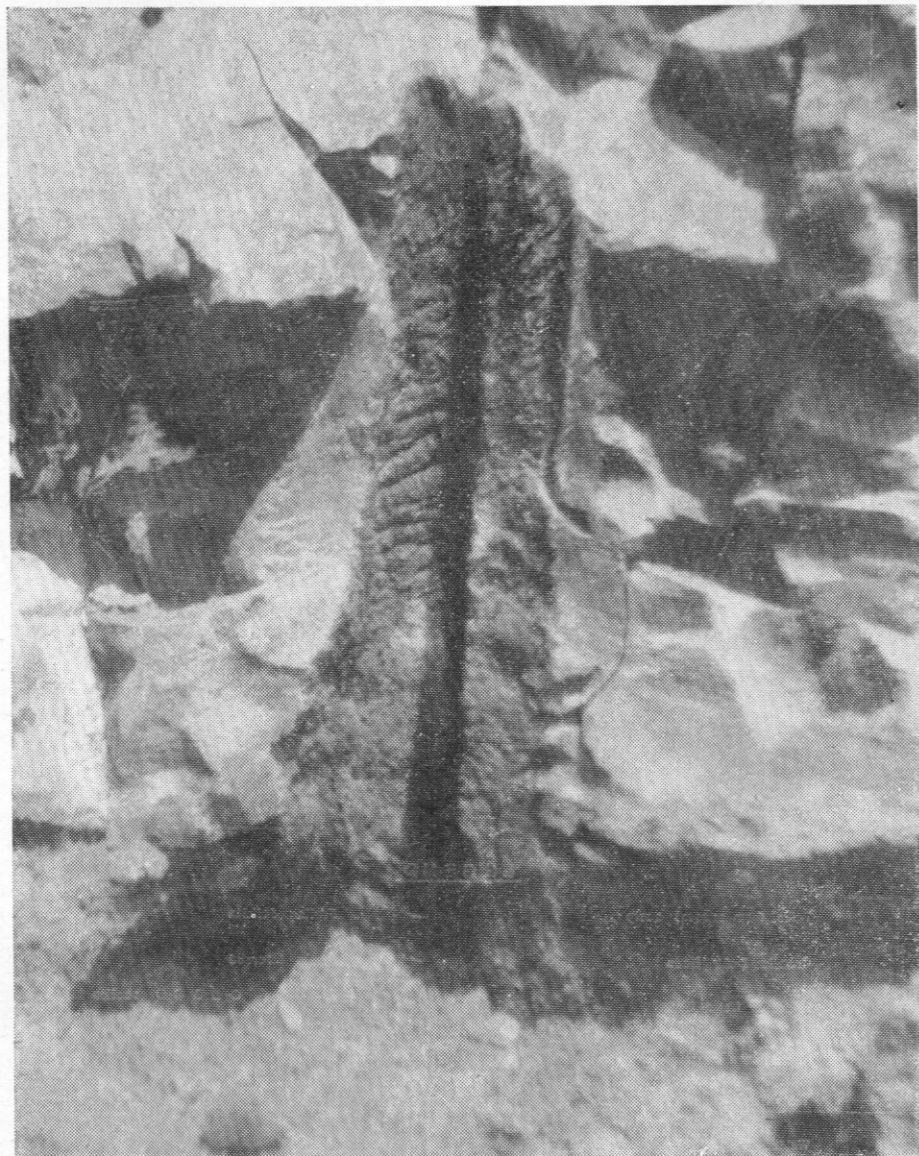


Fig. 1.—Map and serial sections of a small fault block 1½ miles west of Kariandusi. (After B. N. Temperley.)

North of Mbaruk the contrast between the fault cliffs facing the sliver of Mbaruk Basalt at the foot of the Bahati scarp and the gentle slope of the surface of the older tuffs and welded tuffs behind is well seen. Dr. Temperley has suggested the term "Faced fault scarps" for these fault scarps showing a sliver of later lava facing the older cut-back fault line scarp. There is no doubt that failure to recognize this type of feature, which must be common throughout the Rift Valley, may have led in the past to considerable confusion in correlation of the volcanic rocks.

PLATE 1.—The tree moulds in the ignimbrite flow of Menengai



To the south of Ol Punyata Station faulted trachytes are exposed over a wide area, passing under the more recent volcanics of Menengai. There is no welded trachytic tuff overlying these lavas and it seems likely that they are flows of lava erupted at the same

The products of these eruptions may be divided into:—

- (a) *Pumice and Ash Deposits*: mantling the outer slopes, the Rongai and Bahati Plains, and banked up against the Mau Escarpment, together with loosely consolidated boulder tuffs associated with pumice at Lanet, Kariandusi and south of Nakuru.
- (b) *Trachyte Lavas of the Caldera Floor*: erupted from secondary centres within the caldera, and from a few very limited fissure zones on the outer slopes; small cinder cones within the caldera.
- (c) *Active Steam Vents*: within the caldera, with small associated conelets of red siliceous tufa. Very restricted yellow incrustations of sulphur (?) around the actual steam vents.

Pumice and Ash Deposits

The outer slopes of the volcano are mantled by extensive deposits of unconsolidated pumice. The pumice has a very crude stratification, and individual layers are composed of fragments of remarkably uniform size. The fragments rarely exceed an inch in diameter. These pumice deposits have a much greater development on the western side of the crater, where, as noted by Gregory, they have mantled the underlying formations and the finer ashy material has banked up against the Mau scarp on the west side of the Rift Valley. This may indicate an easterly prevailing wind at the time of the emission of the showers of finely divided material that gave rise to these pyroclasts. They form a smooth and level surface mantling subsidence flexures in the underlying lavas of the crater wall, and form deep drifts in the hollow formed by down warping in the course of the subsidence. They are probably contemporary with the caldera formation.

These deposits are of earlier date than many of the secondary flows of the caldera floor, since a flow on the outer slopes north of the Eldama Ravine road, one of the earlier caldera floor eruptions, covered this mantle of pumice. In a small subsidence crater at the caldera rim, this flow is clearly seen resting on a surface of unconsolidated pumice overlying the uppermost glass trachyte lava in the wall. At the edge of this flow, blocks of lava have spilled off, and a loose layer of volcanic boulders rests on the pumice. It is supposed that the eruption which initiated the caldera ejected vast quantities of cinders and ash which covered an enormous area. The finest material is probably represented by red ash with pumice that is banked up against the Mau Escarpment and against the slopes of Kilombe and Eburru. Some coarse fragmental material was also ejected by these explosions since sections in the railway cutting near Lanet show pumice interspersed with tuffs containing rounded blocks of glassy trachyte. Some of this pumice near Mereroni has been partially cemented, probably due to the cementing action of water of the earlier extensive Nakuru Lake. The showers of pumice and ash were succeeded by a renewal of effusive activity within the caldera, giving rise to the extensive trachyte flows that now cover the caldera floor.

Trachyte Lava Flows of the Caldera Floor

The floor of the caldera is completely covered by recent lava flows erupted from secondary centres during periods of renewed activity. There is a central eminence marking the main centre from which these flows streamed down until they were arrested by the caldera wall. There were, however, other eruptive centres since some of the flows have no connexion with the main body of lava that radiates from this centre. For example, the large flow in the "clover leaf" bay at the north-west corner of the caldera is bounded by a terminal cliff facing the centre of the crater. From the form of the pressure ridges a centre near to the caldera wall is deduced.

The flows in the caldera are strikingly different from those forming the walls, although the difference in composition is not great. Most are characteristically blocky flows with surface and terminal cliffs composed of a jumble of loose blocks. Other

flows are glassy in part, composed of obsidian, and show a crude, ropy texture. Bouldery flows with cliff-like, block-strewn edges rising 100 feet above the surface over which they have moved, are widespread. The eruption of lava in a partially solidified state with a very high gaseous content is the accepted mode of origin of such lava flows.

The relative age of the flows within the caldera can be judged from the degree of vegetation cover. The earlier flows are covered by a well-established grass and bush vegetation, from which the pressure ridges stand out as bare crests. The more recent flows have little or no grass cover, the vegetation being restricted to small bushes established in crevices. One flow is completely devoid of cover by vegetation and, from the fresh state of the surface, it seems that the last eruptions of lava took place within the last century. The fissuring of the lava surfaces is so pronounced that walking across them is laborious in the extreme. The writer has taken an hour to traverse a quarter of a mile. The whole surface is thrown up into a remarkable pattern of pressure ridges similar to those found on glaciers. Seen in air photographs these clearly reveal the direction of flow. Near the eruptive centres from which the flows originated this flow orientation is often lost. One such centre consists of a broken field of lava, transected by open fissures more than 100 feet deep. These fissures are mostly oriented north-south which may indicate a relation between the Menengai eruption and the older dislocations of the Rift Valley. Some of the last flows to be erupted emanate in or near definite small cinder cones within the caldera, but eruption appears mainly to have taken place from fissures and small sinks in the surface of the flows rather than from distinct craters.

Lavas of the secondary eruptions are not entirely restricted to the caldera. In two localities eruptions from fissure zones have spilled out trachyte flows on to the outer slopes. A flow on the southern slope, north-west of Nakuru is spectacular, a tongue of ropy lava with a block-strewn surface having spilled down the steep slope, terminating in a low boulder cliff. This cliff, situated on the north side of the Nakuru-Eldama Ravine road, has been extensively quarried, and the nature of the flow is seen in section. The main body of the flow consists of massive black trachyte lava, traversed by numerous shrinkage cracks. The upper surface is ropy and scoriaceous, having a glassy texture, and on this surface a jumble of loose blocks has been carried along with the flow and spilled down the lateral and terminal cliffs. From the nature of the vegetation cover it is deduced that this flow, and a similar flow that has escaped on to the north slope, of equivalent age to the earlier caldera flows. This flow has originated in a north-south zone of instability. At the crater rim the older lavas forming the wall can be seen to have subsided in a narrow zone; the subsidence has produced extensive north-trending fissures, and close inspection of the wall reveals small feeders of recent trachyte penetrating the older lava of the wall. On the surface of the flow there is a line of small, perfectly formed craters, oriented on a north-south line of weakness. In one of these, a cone-like body of recent lava can be seen, penetrating the older streaky trachyte exposed in the wall. The walls of these craters are vertical and they are attributed to abrupt subsidences, forming orifices through which lava has risen to feed the overlying flow.

Some cinder conelets occur within the caldera surrounded by the recent flows of lavas. They are in the form of conical heaps of scoriae, up to a few hundred yards in diameter. The grass-covered mound that forms the secondary summit (6,858 feet) has no central depression but the crude cone to the east, from which a large lava flow emanates, has a well-marked central hollow.

Active Steam Vents

Within the crater, steam vents are still active in restricted localities. The steam issues from small fumaroles, about two inches in diameter, emerging only under very slight pressure. Mr. Thornhill, who has farmed on the edge of the crater for

30 years, has observed a definite variation in activity according to the hour of the day. A similar hourly variation is seen in the activity of numerous fissures blowing cold air in the neighbourhood. It seems probable that changes in atmospheric pressure are responsible for this regularity of behaviour.

These steam vents have built up mounds of a light-red siliceous tufa. In one case the tufa mound has the form of a conelet. The largest of these tufa mounds forms an elongated ridge several hundred yards long, with numerous fumaroles situated in the tufa along the crest of the ridge, but there is no central depression. The actual vents are often encrusted with a yellow deposit, probably sulphur, but there is no evidence of sulphur deposits of any magnitude. Boreholes two miles north of the caldera have encountered steam under low pressure at 200 feet.

CHAPTER VI—THE EBURRU AND ELMENTEITA VOLCANIC SERIES

The Eburru Volcanic Series

The great twin-peaked volcano of Eburru is outside the area covered in this survey. Lava flows from the volcano have, however, been mapped on the extreme southern margin of the area. These can be divided into two groups:—

- (i) Older porphyritic trachyte lavas.
- (ii) Newer glassy trachyte and trachy-obsidian flows.

The Eburru volcano is later than the grid faulting, but the first group is affected by substantial posthumous fault dislocations, whilst the second group is only affected by minor fissuring. The first group of lavas show a striking similarity to the earliest porphyritic trachyte lavas of Menengai.

The Elmenteita Volcanic Series

The cluster of comparatively small volcanoes south of Lake Elmenteita have been referred to by Gregory as a group of broken basalt craters rising from the Elmenteita alluvium. He also mentions the connexion of the Eburru Station steam vents with north-south faulting. The whole complex of volcanic cones and basaltic flows is illustrated in Map No. 4. It is evident that there are several series of volcanoes in this locality. The Eburru peaks are two comparatively old and dissected volcanoes. The ridge formed by these peaks traverses the Rift Valley in an east-west direction, whilst the more recent Elmenteita volcanoes are restricted to a north-south zone about five miles wide cutting across the eastern shoulder of the Eburru ridge. This line of volcanoes continues southwards towards Lake Naivasha, but only the area north of the old railway alignment is described here.

The volcanic eruptions may be divided as follows:—

- (i) Small Tuff Volcanoes, broken by north-south faults of restricted throw.

Basaltic Tuffs (tB). Buff and grey in colour, crudely stratified, often with included angular blocks or boulders of phonolitic trachyte, porphyritic basalt (Mbaruk type) and vesicular basalt of similar type to that described below.

Basalt Flows affected by north and south faulting of restricted throw (and included boulders in tuffs). Vesicular basalt—(Be') rough and comparatively coarse textured in hand specimen, numerous large individual crystals set in a glass ground mass, prominent rounded vesicles.

- (ii) Basaltic cones with distinct and well-preserved craters composed dominantly of red scoriaceous cindery basalts, cindery flows sometimes exposed in the crater walls, outer slopes mantled in loose cinders derived from the waning stages of eruption.

Basalt Flows, rough textured, black in colour, with numerous round vesicles. Several successive flows superimposed on one another, Be^A, Be^B, Be^C.

Small broken volcanoes, probably of similar date to the tuff cones composed of whitened basaltic pumice.

- (iii) A recent basalt cone, a mile north of Eburru Station, similar to the other cinder cones but the almost perfectly preserved form suggests that it is the most recent volcano of any size in the vicinity. This is borne out by the fact that it is situated on the edge of a zone of thermal activity.

Very recent flows of grey or black basalt with poorly established vegetation cover; glassy in texture and characterized by elongated vesicles, porphyritic in part.

Flows of glassy black basalt with prominent ideomorphic felspar phenocrysts, in dike-like bodies, filling irregularly orientated fissures in the crater of the volcano named "High".

The Tuff Cones and Associated Basalt Lava

Tuff cones make up the greater part of the earliest phase of renewed vulcanism near Lake Elmenteita. The associated lavas have mostly been obscured by subsequent eruptions and a cover of lake beds, but no doubt they covered a considerable area. Basalt flows which outcrop in the vicinity of Lord Delamere's house at Soysambu probably represent these lava eruptions, since, unlike the remainder of the Elmenteita basalts, they are transected by minor north-south faults. The presence of basalt of similar type in the boulder beds intercalated in the tuffs forming the cones, shows that the earliest effusions of a vesicular basalt were at least simultaneous with, if not earlier in time than, the formation of the cones.

The volcanoes of this group are all very steep sided and formed of crudely stratified tuffs, dipping steeply outwards at inclinations of 30 to 40 degrees. The tuffs are horizontally disposed on the crest of the crater rim and dip inwards at an equivalent angle of inclination on the inner wall of the crater.

Boulder tuffs containing fragments of phonolitic trachyte and Mbaruk Basalt are often seen in these cones indicating that the formation of the craters was accompanied by the explosive eruption of fragmental material. Some cones, however, are entirely composed of finer tuff. The majority of the cones in this group are transected by north-south faults which downthrow the median sector of the cone, leaving the lateral sectors standing above a median trough. The occurrence of these sharply downthrown fault troughs is indicative of the subsidence subsequent to volcanic eruption. The craters represent vents situated on north-south fissures, and the explanation may be that these vents enlarged longitudinally as the explosive eruptions continued along the line of the fissure. The structure is comparable in origin to subsidence calderas. It may well be that these structures have a similar origin to some of the major fault troughs of the Rift Valley, the process being here seen in microcosm. This has been suggested by Shand [11] in a brief note on the Rift Valley of Kenya. The absence of lithic material in these cones, except for angular blocks of the underlying country rock suggests that these cones may well represent explosive phreatic eruptions caused by water from the lakes seeping down reopened, deep-seated fissures and coming into contact with very hot lava. It is noticeable that these small explosion vents are clustered in lake basins and are not found elsewhere.

The cone at Honeymoon Hill, south of Nakuru Town, and the small fragment called Crescent Hill, immediately to the east, are very similar to the Elmenteita cones and must be considered as part of the same closely related eruptive series. The median fault trough is not so distinct on Honeymoon Hill, but the cone is transected by small north-south faults of small throw. The blocks included in the tuffs are composed of vesicular basalt and porphyritic trachyte.

These cones show lake-shore lines identified as Gamblian midway up their slopes, and are believed to be of Kanjeran age.

The problem of the time relation between these cones and Menengai is not easily solved. However, the Eburru volcano is definitely older than the Elmenteita craters, and since porphyritic trachytes, identical with those of the first Menengai eruption, outcrop on the slopes of Eburru, it is concluded that the first Menengai eruptions may possibly have preceded the first Elmenteita basalt eruptions.

The Basalt Cinder Cones and Associated Vesicular Lava Flows

These have a much smoother and more rounded profile than the tuff cones. No faults disrupt their slopes, which show outcrops of red basalt cinders instead of dip slopes of tuff. One of the most westerly and the largest of these cones appears to have a double crater; a later and perfectly formed crater lying within an earlier, larger and more elongated orifice. It is possible, however, that this nested appearance is due to subsidence of the median sector as in the case of the earlier tuff cones. No fault planes can, however, be made out and the walls of the outer hollow have a distinctly curved trace. Several lava flows are exposed in the wall of the central crater. These are of grey scoracious basalt with prominent, clear, felspar insets.

Microscope slides indicate a considerable degree of cataclasis. Two of these cinder cones are isolated within a very recent lava flow. They can be seen to be cones of similar type to the one referred to above, but owing to difficulty of access were not examined in detail. Smaller cones near the shore of Lake Elmenteita show no distinct crater, consisting simply of conical piles of red cindery basalt.

The connexion between the unfaulted vesicular basalt flows and individual volcanoes is obscure, but it is clear from the map that there is an areal relationship. Thus it seems likely that the earliest group of unfaulted flows emanated from these craters. A vast tract on the south and west sides of Lake Elmenteita has been overridden by these flows. They cover the earlier deposits of the Nakuru-Elmenteita basin but have to some extent been subsequently covered by a thin and discontinuous mantle of lake deposits at a recent date when the lake waters covered a larger area.

The Basalt Scoria Volcano near Eburru Station and Associated Vesicular Flows

This is a perfect cone, undisturbed by faulting, having cinder-covered slopes much steeper and more regular than any of the other basalt cinder cones. It has a deep crater some 200 yards in diameter. Red cindery basalt is exposed on the crater wall. There is a smaller parasitic vent immediately to the north of the volcano suggesting an even more recent eruption on the fissure line after the main vent had been plugged.

The most recently erupted basalt lavas differ from the earlier flows in the presence of very characteristic elongated vesicles, and a glassy texture. In colour they are generally lighter than the earlier erupted vesicular basalt of recent age. From the slope of the surface of this latest flow, the source would appear to be the Eburru Station Volcano. Another separate flow of this lava flows down to the south from a small cone of red cindery basalt. These flows are covered only by a coarse Euphorbia scrub and, from the degree to which vegetation has established itself, would appear to be of similar age to the earlier secondary eruptions of the Menengai centre.

The Eburru Steam Zone

This lies within the Elmenteita zone of posthumous faulting and vulcanism. Numerous active steam vents are seen immediately north of the railway. No evidence of steam activity has been observed in the craters or in the surface of the lava flows further north. The steam vents occur along well-defined north-south surface fissures.

The Origin of the Elmenteita Volcanic Zone

From a study of the fault structures near Gilgil and Soysambu it can be deduced that Elmenteita lies in a graben formed in the Lower Pleistocene or Lower Middle Pleistocene epoch. Similar fault troughs are those of Solai and Lake Nakuru. In these troughs fissuring is widespread and there is strong evidence of present-day crustal instability. In the Nakuru fault trough only Honeymoon Hill provides evidence of a renewal of volcanic eruption, though the recent eruptions and steam zone of Menengai are probably related to the northward continuation of the same trough. The Solai fault troughs show evidence of very recent crustal instability but no recurrence of vulcanism. The Elmenteita trough appears to be one of the least stable in the Rift, and has been the focus of repeated recurrences of volcanic eruption. Present-day steam conditions testify to the continued activity. This line of instability and thermal conditions probably continues southwards over the shoulder of Eburru, and through Lake Naivasha to the vicinity of Hell's Gate (Njorowa Gorge).

CHAPTER VII—THE SEDIMENTS

The sediments may be subdivided as follows.

- (i) Reworked tuffs and clays, intercalated in the older tuff formations of the Mau and Bahati Escarpments.

Yellow to buff sediments; some fragments showing rounding by water abrasion; clayey matrix.

- (ii) Sediments intercalated in the older-faulted lava flows of the Rift Valley floor.

Similar to the above, but water rounding more marked.

- (iii) Lake sediments of the Pleistocene Lake of the Nakuru-Elmenteita Basin.

Yellow-buff volcanic grits, reworked tuffs, clay, diatomite.

The first two groups, intercalated in strongly faulted volcanic rocks bear little relation to the present-day topographic features or drainage basins. They are, however, important in that they provide the aquifers within the faulted rocks. The third group of sediments were deposited in a drainage basin closely resembling that of Lakes Nakuru and Elmenteita at the present time, but modified by minor faulting and warping movements.

Kanjeran Sediments

The conclusion has been reached that there were two major faulting episodes in the Rift Valley. The second of these disrupted the extensive basalt and phonolitic trachyte lava flows covering the valley floor, forming a series of horst and graben structures. It is upon this serried surface that the earliest Pleistocene lake sediments were deposited. These sediments, the Kanjeran Lake Beds, are exposed at Kariandusi, on Cole's Farm further north, and at Soysambu (according to Solomon, Leakey and Nilsson). Solomon identified tuffs on Cole's Farm as Lower Kamasian;* a point of great significance, since these reworked tuffs appear to be continuous with the coarse, crudely stratified basaltic tuffs that built High volcano and the other yellow tuff cones of Elmenteita. (The distinction between tuffs and lake beds in this locality is quite arbitrary.) The tuff cones of Elmenteita are thus thought to be of Kanjeran age.

The Kanjeran Sediments of Kariandusi, and the tuffs of these cones are affected by minor faults; posthumous dislocations on the earlier lines of weakness. The fact that Kanjeran diatomitic lake beds are displaced by a fault of more than 100 feet throw at Kariandusi has been taken by Solomon and Leakey to indicate that the Gilgil fault scarps are among the latest in the Rift Valley. However, a study of High volcano on Cole's Farm south of Kariandusi reveals a major fault scarp of trachytic

* At the time of the revision of this report in 1957, before publication, the sediments here referred to as Kamasian had been ascribed to the Kanjeran stage by Leakey . . . , i.e. Upper Middle Pleistocene, slightly later than the Kamasian. They are referred to as Kanjeran in the subsequent text.

lava over 200 feet high, obscured by the tuffs of this volcano which have banked up over the fault scarp. These tuffs have been faulted, owing to a major posthumous movement along the same lines, but they are not displaced more than 30 feet. The downthrow of 100 feet at Kariandusi is extreme for one of these minor posthumous faults, but it must be noted that the Elmenteita Zone has been the site of repeated vulcanism over a considerable period during the Pleistocene and it is logical to expect late subsidence movements to be at their greatest development in this zone. Shackleton (1955) in a paper published after the production of the original limited edition of this report states that the throw of "fifty metres" on the fault displacing the diatomitic sediments at Kariandusi is much less than the displacements affecting the trachyte flows which form the lines of lava ridges, and he concludes (like the writer) that the diatomite was deposited on a surface of faulted lava, and was later subjected to minor faulting.

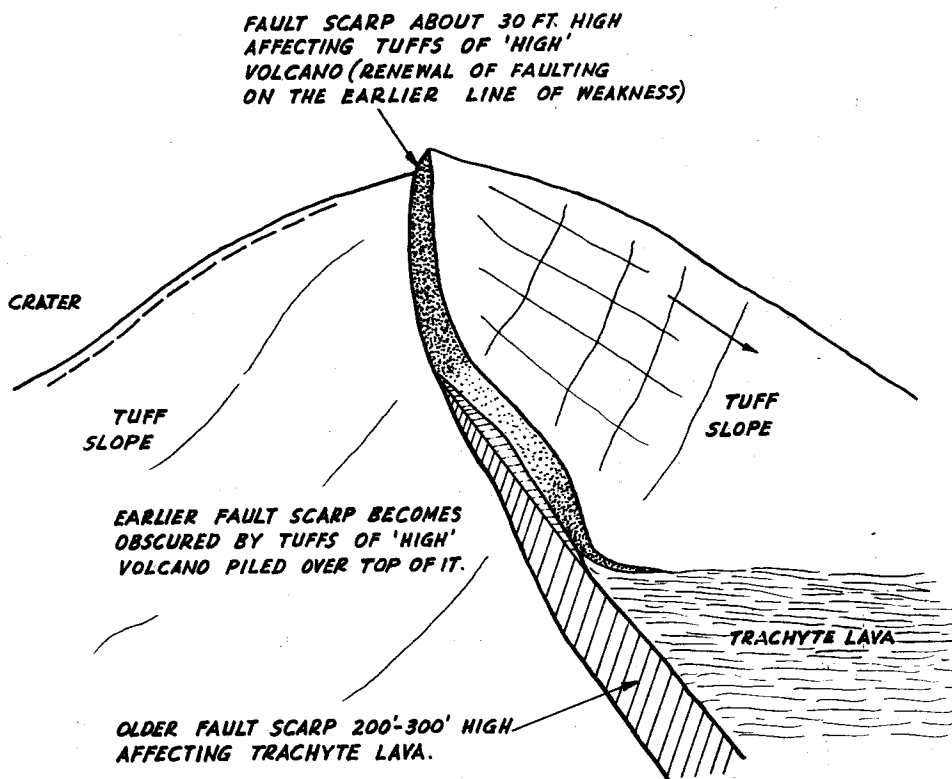


Fig. 5.—Sketch showing the renewed faulting of basaltic tuffs of "High" volcano—a posthumous adjustment on an older major fault zone.

The Gamblian and Makalian lake beds have been differentiated by Nilsson into seven distinct lakes, from correlation of shoreline terraces. The first Gamblian lake extended over the shoulder of the Gilgil Escarpment, the Naivasha and Nakuru basins being joined in one great lake.

This Gamblian lake left a shoreline terrace on the Elmenteita tuff cones and on the slopes of Menengai. The early phase of eruption from Menengai must certainly be pre-Gamblian and possibly pre-Kamasian. Mr. Lepersonne of the Belgian Congo recently visited Menengai and considered that the state of erosion of the inner cliffs indicated an almost historic age. Such a dating is, however, in conflict with all the other available evidence.

Subsequently a succession of lakes were formed in the wetter periods, the trend being towards less and less extensive lakes until the very restricted lakes of the present day were left. (See Figs. 6 and 7.)

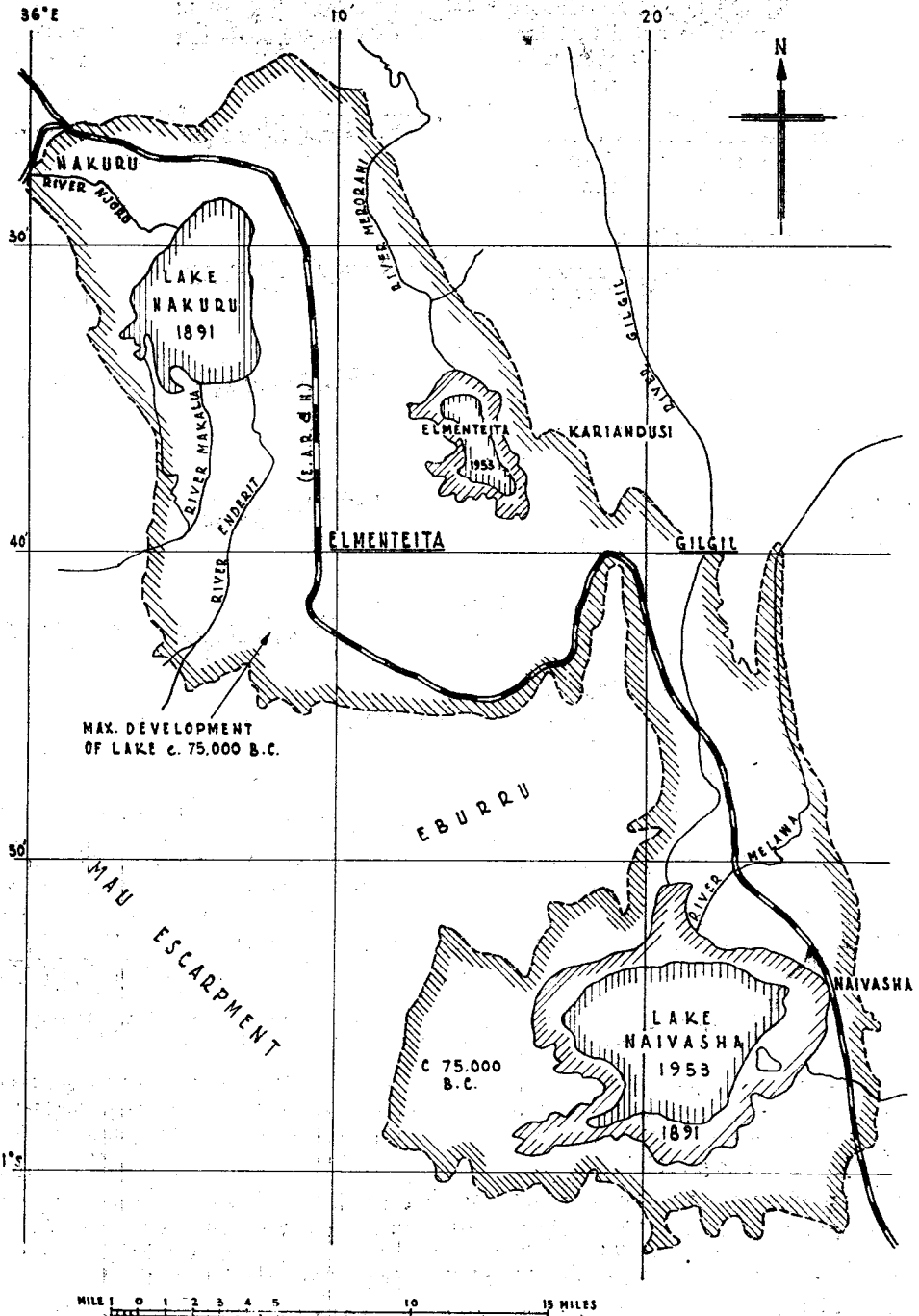


Fig. 6.—Sequence of changes of the Rift Valley lakes. (After E. Nilsson.)

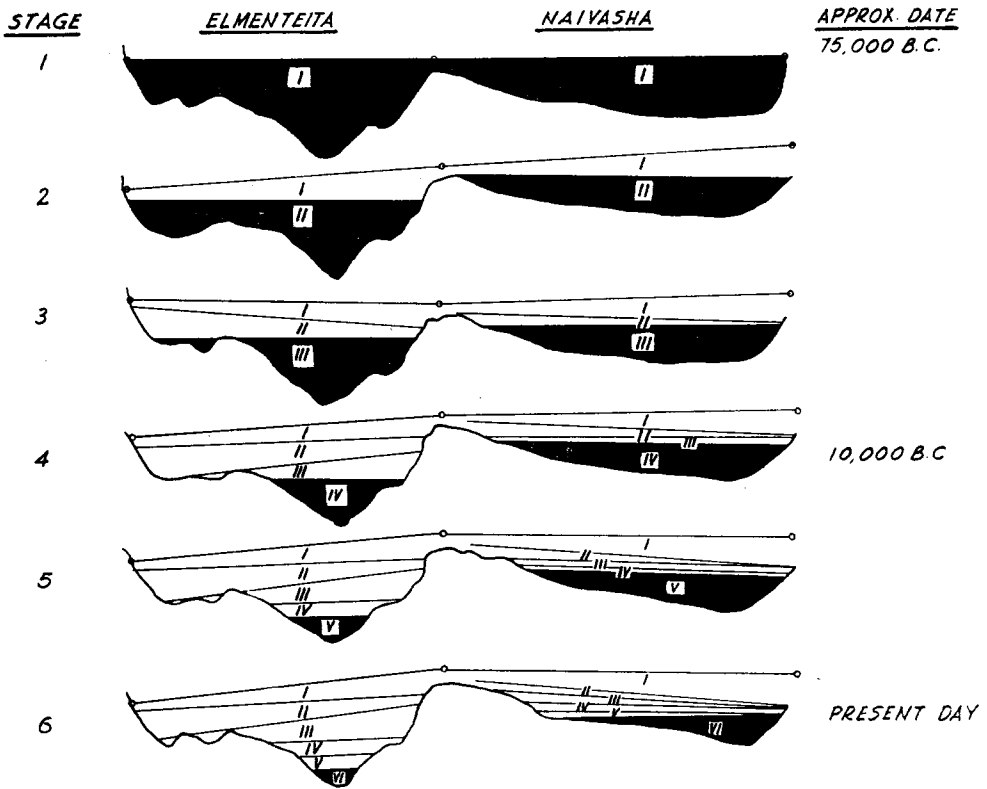


Fig. 7.—Sequence of changes of the Rift Valley lakes. (After E. Nilsson.)

The Makalian lake beds are overlain by a deposit of consolidated grey tuff known locally as building stone. This tuff extends as far as Njoro, Elburgon and Rongai, and is concentrated in the present-day valleys having apparently been washed in by rain after the existing drainage pattern has been initiated. This tuff closely resembles the glassy tuffs that form scattered outcrops on the east side of Menengai. They are the uppermost consolidated volcanic rocks, on the slopes of Menengai, and have been taken to represent the products of the explosive eruptions coincident with the first stages in the formation of the caldera. They are never seen within the caldera. If this assumption is correct the formation of the caldera occurred after the Makalian subdivision of the Pleistocene not more than 10,000 years ago, and the process was completed considerably later, though how much later cannot be estimated.

The Makalian ash deposits are affected by minor faults posthumous on the earlier lines of weakness. These may well be part of the same system of subsidences which formed the caldera.

The glassy tuffs east of Menengai (correlated with the Makalian ash) are overlain by the extensive unconsolidated pumice deposits. These form a mantle over the western slopes of Menengai, and are banked up against the Mau, Kilombe Hill and Eburru. The recent shoreline terrace 145 feet above Lake Nakuru dated as Nakuran is composed of coarse pumice clearly derived from these pyroclastic deposits.

The deposits of the present-day lakes are mainly composed of fine clay, silt and volcanic sand.

CHAPTER VIII—TECTONICS

It must be accepted that the Rift Valley is essentially a tectonic structure. The imprint of such a regular pattern of linear troughs by erosional processes on the centre of the African continent is inconceivable. In the Nakuru area the following tectonic episodes can be recognized:—

- (i) Major faulting, originating the Rift Valley. Fault zones of enormous displacement along the line of the Mau Escarpment and the Bahati-Subukia Escarpment. The actual faults are mostly obscured by later eruptives and the faults are now represented by fault line scarps. (Miocene?)
- (ii) Major faulting further breaking up the scarps formed during the original faulting episode; disrupting the lavas covering the valley floor into a complicated series of horsts and grabens. Renewed movement on older bounding faults. (Pliocene or earliest Pleistocene?)
- (iii) Minor renewals of faulting along the earlier lines of weakness. (Pleistocene?)
- (iv) Fissuring and very minor adjustments accompanied by earth tremors continuing at the present day. (Recent.)

The evidence for the two major faulting episodes has largely been dealt with in the discussion of the relationships of the various volcanic formations. The earlier faults are not exposed, and the majority of the major faults seen in the area are attributed to the second episode of faulting. There is a slight variation in trend of the faults of the second series. The Mau Escarpment shows a west-north-west-east-south-east deviation between Molo and Njoro—while the Bahati-Subukia Escarpment trends north-west to south-east. This latter escarpment is cut up into a series of north-south troughs by later faulting. This is particularly well seen between Mbaruk, Kariandusi and Gilgil where the older fault scarp is repeatedly offset by north-south faults, bringing the lavas of the Rift Valley floor into contact with the older tuffs of the escarpment.

Posthumous faults affect the glassy tuffs of Menengai near the Crater Stream and west of Mbaruk. The Makalian ash east of Njoro is also similarly disturbed. The Kanjeran lake beds and the tuff cones of Elmenteita are displaced by faults of similar magnitude. Some of these later fault movements apparently coincided with the large-scale subsidence of Menengai within the last 10,000 years.

The concentric pattern of faults and monoclines to the north of Menengai is believed to have been imprinted on the older north-south fault pattern concurrently with the caldera formation. The trough faults that cut across the median line of the Elmenteita tuff cones (Kanjera?) are thought to be earlier structures due to subsidence immediately after the explosive eruptions ceased in these volcanoes.

Fissures and very minor faults cut recent pyroclastics exposed in a railway cutting at Mereroni (Lanet). Further evidence of recent movement is seen in the form of surface fissures most frequently found in the centre of fault troughs. On Milton's farm at Solai these are most strongly developed. On this farm there are some small vertical fault planes exposed, the soft Solai tuff showing no degradation by erosion. A zone of recent fissuring crosses the Njoro River east of Glanjoro Farm. Earthquakes are not unknown in the Nakuru area and tremors are frequent in the Solai Valley. Though earth movements are at present of a very small order, it is evident that Nakuru is situated in a zone of crustal instability and there is a possibility of the recurrence of catastrophic earthquakes.

The Nature of Fault Movements

The apparent relation of the Rift Valley system to previous tectonic structures has been discussed by Shackleton [3] and McConnell [4]. Considering the Tertiary structures, for which many theories have been advanced, the only type of dislocations exposed on the surface in the Rift Valley are steep normal faults. The actual fault planes are not very frequently exposed, but where they are there can be no doubt as to their nature. The fractures are open and usually filled with rubble. The whole pattern of the faulting suggests simple gravity collapse. It is suggested that the most recent minor faults may be caused by subsidence of the crust subsequent to extrusion of great volumes of lava and tuff.

The tilting of the fault blocks downwards away from the scarps is a marked feature of the grid structure of the Rift Valley floor. It is identical with the structure described by Le Conte [10] in the Basin Range of North America, and suggests that magma rose near to the surface, the fault blocks, already opened up by tension, adjusting themselves to a position of equilibrium while floating in a liquid magma. The grid faults must penetrate to great depths if this condition existed.

The oldest faults, boundary faults to the original fault trough, are obscured. The nature of these earliest faults is not evident from a study of this area.

The trapezoidal shape of the Menengai caldera clearly reflects a control exerted by the old fault line scarp running north-westwards towards Ol Punyata, and the later (Lower Pleistocene (??) fault trough which run north-north-eastwards towards Laikipia from Menengai. The interesection of these two fault lines may indeed be causally related to the presence of the caldera at this point. The pattern of the grid faulting and later faulting north of Menengai shows the dominant north-south trend and also an oblique north-westerly trend which can be interpreted as posthumous movement following the line of the oldest known fracture system.

Conclusion

It is the conclusion of the writer that the whole complex structure of horst and graben, grids, etc., is superimposed upon an older fault trough. The cause of the formation of the original fault trough and the nature of the faults is obscure, but there is no evidence of compressional structures and the probability is that they are normal tension faults. The second (grid faulting) episode was apparently caused by a renewal of tension: the several minor recurrences in more recent time are attributed to gravity adjustments, consequent on volcanic eruption.

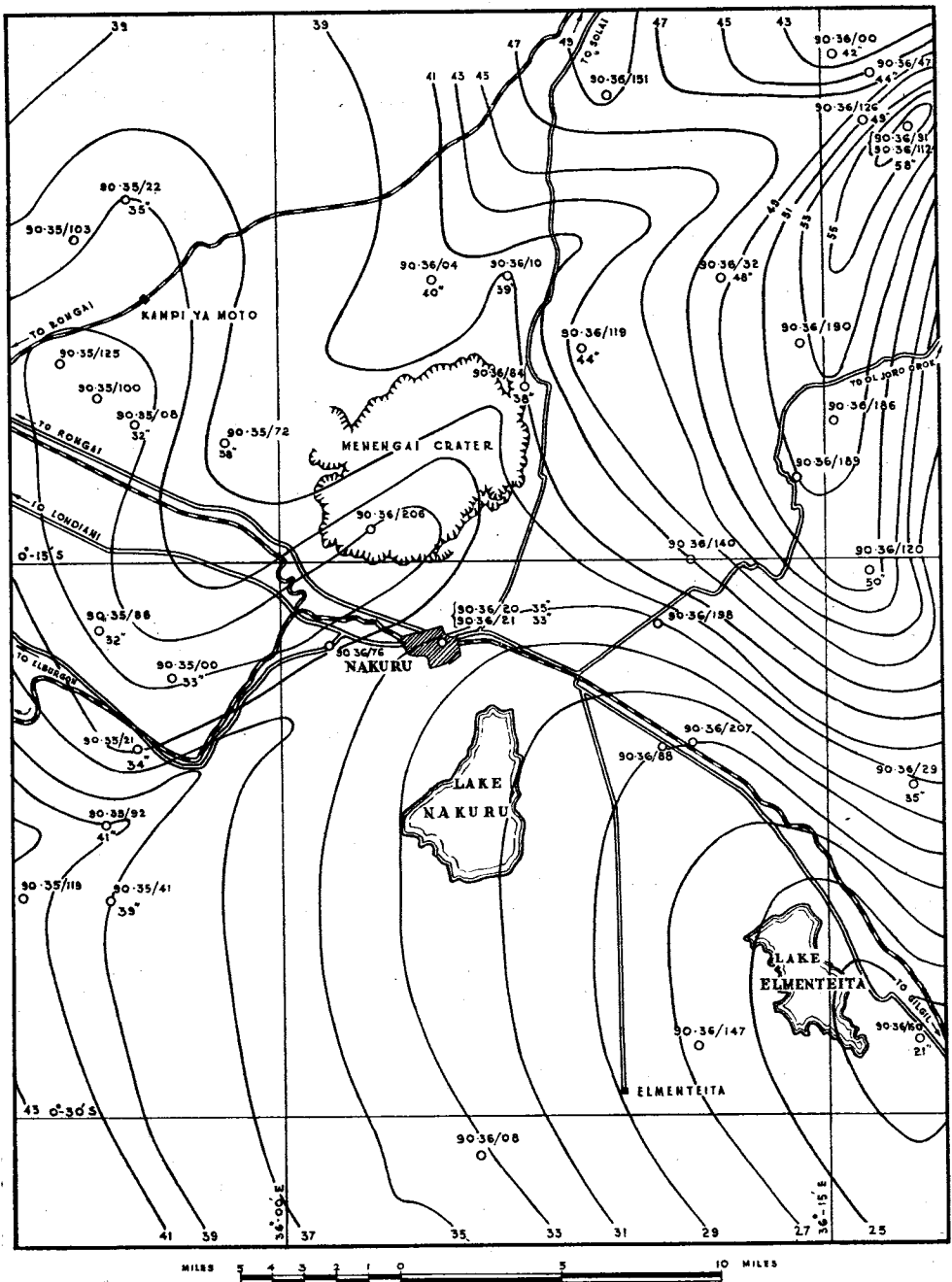
CHAPTER IX—HYDROLOGY

Rainfall

Typical annual rainfall figures for the Nakuru area are given below. It is seen that the rainfall on the forested high ground of the Mau and Bahati rises to 50 inches and more, while on the floor of the Rift Valley average readings vary between 25 and 35 inches per annum.

The rainfall is mainly in the form of heavy thunderstorms in the wet months, March/April and July/August.

Fig. 8 shows the Isohyets for the Nakuru drainage basin.



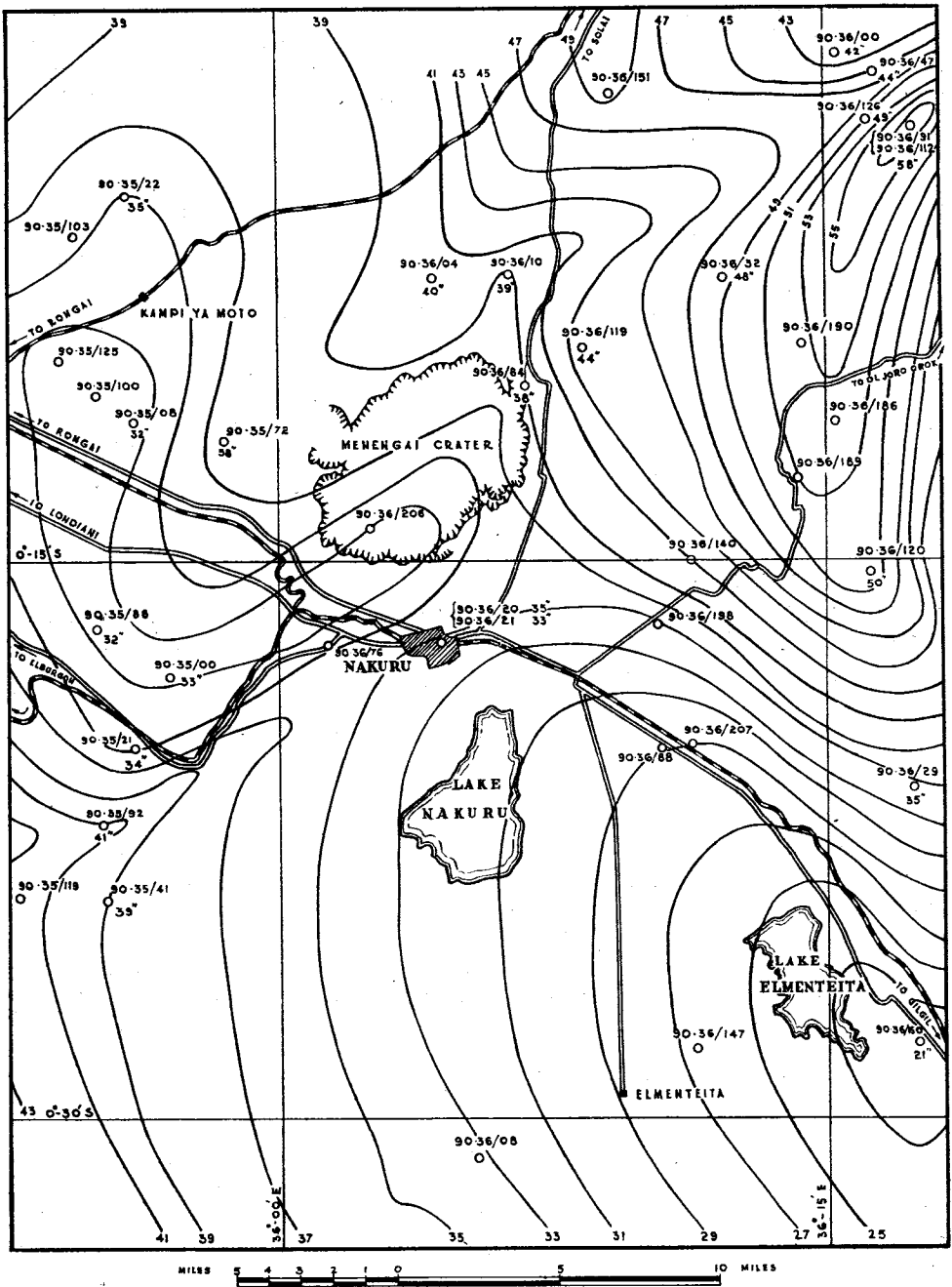


TABLE IV

STATION					Period over which Average taken	Average Rainfall in inches
A.—MAU—						
Molo (Railway Station)	..	..	..	..	46 years	50·43
Elburgon (Mariashoni)	..	..	..	..	2 „	48·63
Elmenteita (Mau Narok)	..	..	..	..	27 „	41·51
Njoro (Plant Breeding Station)	..	..	..	..	23 „	36·24
B.—BAHATI—						
Nakuru (Bahati Forest)	..	..	..	..	20 „	48·11
C.—RIFT VALLEY FLOOR—						
Rongai (Gogar)	..	..	..	..	21 „	34·38
Kampi-ya-Moto (Rongai Bdg.)	..	..	..	..	38 „	34·95
Solai (Rhodora)	..	..	..	..	14 „	37·09
Solai (Ol Punyata)	..	..	..	..	34 „	40·45
Nakuru (Met. Station)	..	..	..	..	34 „	34·59
Elmenteita (Soysambu)	..	..	..	..	15 „	26·37

The Hydrological Cycle

The Rift Valley contains a system of internal drainage basins, with no outlet to the sea. The hydrological cycle as envisaged in one of these basins is illustrated in Fig. 9.

FORESTED WALLS OF THE RIFT VALLEY

FLOOR OF THE RIFT VALLEY

LAKE

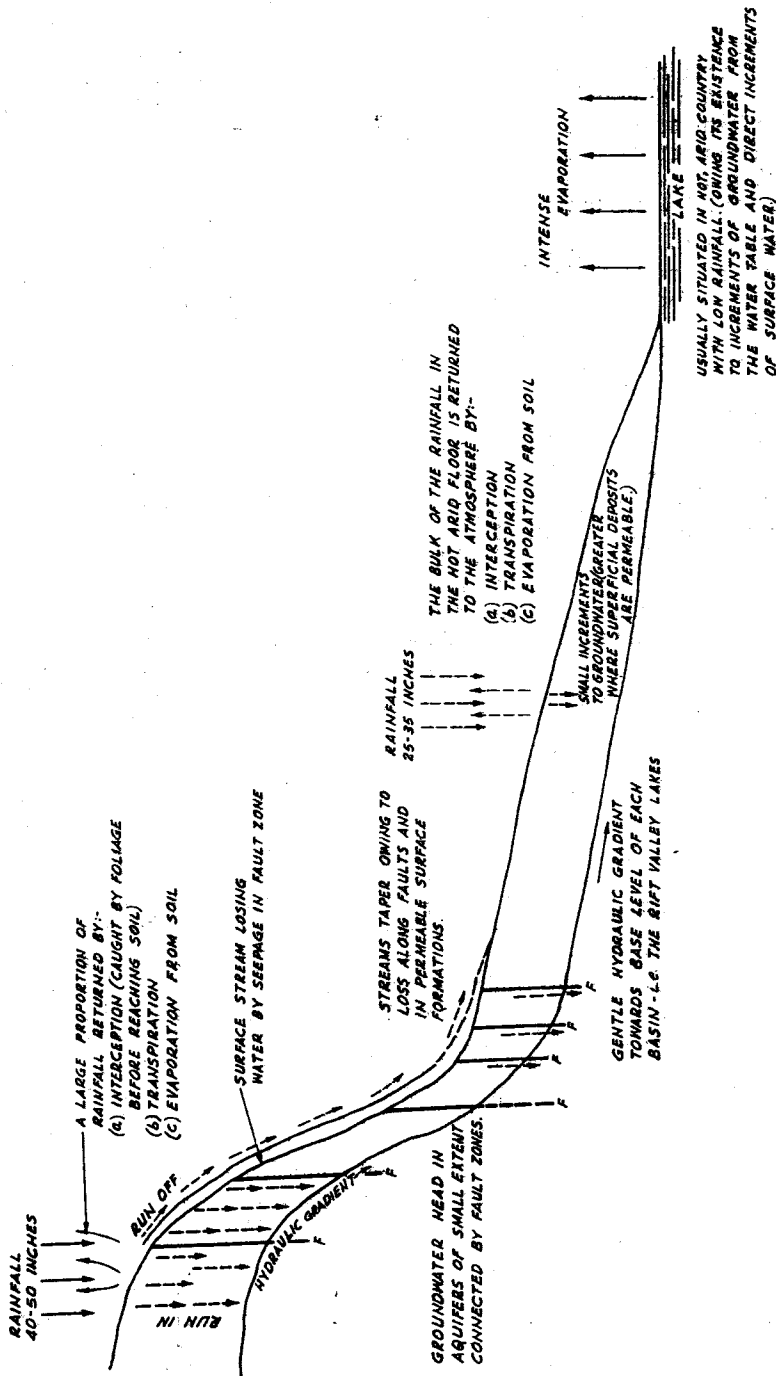


Fig. 9.—Diagrammatic representation of the hydrological cycle in the Rift Valley.

The main basins in the Kenya Rift Valley are the Naivasha Basin, the Nakuru-Elmenteita Basin and Hannington-Baringo-Rudolf Basin. The watersheds are the Eburru Ridge and the Menengai-Njoro Ridge. The possibility of subterranean outlets between these basins must be considered. It is possible that there is an underground flow between Naivasha and Elmenteita, but not enough is known of the area between the two lakes to provide any evidence at the present date. From the form of the piezometric contours at the northern end of the Nakuru Basin it seems unlikely that there is any outlet under Menengai. The water in Borehole C.1246 at Nakuru Show-ground stands 4 feet above the level of the lake floor, indicating a very gentle hydraulic gradient southwards towards the lake.

Owing to the extremely variable nature of the geological formations, and the lack of data, no more detailed account of the hydrological conditions can be attempted at the time of writing.

CHAPTER X—HISTORY AND RESULTS OF GROUNDWATER DEVELOPMENT

Past History

The conditions governing the occurrence of groundwater in the Colony were described by a former Director of Public Works, H. L. Sikes, in a memoir published in 1934 and entitled *The Underground Water Resources of Kenya Colony*. Knowledge of the subject was extremely limited at the time with only some 200 boreholes drilled in the Colony. These were restricted to the few areas in which the need for water was extremely pressing. Between 1934 and 1953 2,000 more boreholes have been drilled, with a considerable extension of our knowledge of the potentialities and mode of occurrence of groundwater over many parts of the Colony.

At the time of Sikes's survey only 23 boreholes had been drilled in the Rift Valley. Of these, only eight were successful, four of which were in the Kamasia Reserve. These very poor early results were due to a concentration of boring operations in the Kedong sector, where steam conditions and very deep water table conditions predominate. Failures were also caused by the fissures encountered during drilling operations.

Sikes based his general conclusions regarding groundwater potentialities of the Rift Valley on the very meagre evidence provided by these 23 boreholes. His conclusions were affected by two misconceptions. Firstly, he overestimated the thermal conditions. It can now be demonstrated that the steam areas are limited to the immediate vicinity of recent centres of vulcanicity, though high temperature conditions are widespread throughout the Rift Valley. The second, and far more significant, misconception was the idea that the groundwater of the Rift Valley is an entirely separate system from that of the high country flanking it on either side. It is one of the facts most clearly demonstrated in the present survey that the Rift Valley in the Nakuru area, though an area of internal surface drainage, obtains its main recharge of groundwater not from the rain that falls within it, but from the rain that waters its high flanks, the Bahati Forest and the Mau. Sikes appears to have underestimated the volume of recharge available from these forested flanks, and he considered that any water reaching the valley floor would at once sink to great depths to be later returned to the atmosphere as steam from invisible fumaroles.

It was not until after 1940 that drilling on a large scale commenced in the Colony, and then the potentialities of the Rift Valley were revealed. Boreholes drilled by J. A. Macdonald and H. H. Kjaertinge proved the existence of groundwater in quantity and at reasonable depth in the Nakuru basin and on the Rongai plain. Drilling at Elmenteita proved the existence of large supplies in the thick sedimentary deposits of the lake basin. Interest in boring for water was aroused, and widespread boring operations in the succeeding years have revealed that favourable aquifers in the form

of sedimentary intercalations and old land surfaces separating the lava flows are ubiquitous throughout the volcanic rocks in the area. The main cause of boring failures in volcanic or sedimentary rocks is a condition where the hydrostatic (or piezometric) level is too deep for water to be obtained within practical depth limits, and in no way due to the absence of favourable geological formations.

Drilling operations in the Solai Valley lagged behind the remainder of the area. An early attempt in 1930 on the farm of A. J. Simpson near Ol Punyata produced steam under low pressure, and though ten years later Manuel and Keppe drilled successfully close to the Tindaress River near Solai Police Post, this was apparently regarded as a rather fortuitous tapping of a river seepage. The Solai Valley was considered an area of little potentiality for many years because of the proximity of Menengai and the fact that resistivity depth probes yielded low-value curves completely devoid of any indications. Up to 1952 only five boreholes had been drilled in the valley (excluding the vicinity of Lake Solai) of which only one was successful. Successful results were then obtained on subsidized sites at Tindaress and on the farms of G. B. Ireland and B. McKenzie. Drilling was carried out by an enterprising drilling contractor on farms where subsidy had not been granted for C. M. Brown, H. H. Peet and Mrs. Hawkins and the tested yields of each of these seven boreholes exceeded 20,000 gallons per day, demonstrating that the Solai Valley, far from being an unfavourable area, is, in fact, an exceptionally good area for drilling. Subsequently boreholes drilled on farms of W. B. Prentice, J. Seys, J. Eames, K. E. and R. H. Adams and P. E. L. Howard have revealed that on the eastern and south-east side of Menengai water-tables at reasonable depth exist close to the rim of the caldera. The borehole on the farm of J. A. Seys is situated on a collapsed block of land virtually within the caldera while Prentice's borehole is but 1,500 yards from the 300-foot cliff bounding the crater.

Drilling in the Kampi-ya-Moto area has always been attended by total failure, though success has been achieved further north in the Kamasia Reserve (C.711) and at Lomolo. The reasons for this failure are considered in another section of this report. No great hope of success in this area can be entertained. It is just possible that water might be obtained in some parts by drilling to nearly 1,000 feet, but the hydrostatic level is so deep that pumping would be both difficult and expensive.

In Elmenteita drilling has been virtually 100 per cent successful. The thick series of Pleistocene lake beds provide excellent aquifers. As would be expected, however, many of the boreholes near the lake yield water of a highly mineralized character.

CHAPTER XI—DESCRIPTION OF AQUIFERS

In the area under consideration the geological formations are limited to the Kainozoic volcanic rocks (more correctly defined as Tertiary-Quaternary, since eruptions of lava have continued up to the last few hundred years) and sedimentary deposits, mainly of lacustrine origin, extending in time of deposition from the Tertiary era to the present day.

The volcanic formations consist of basalt, phonolite, phonolitic trachyte and trachyte flows, together with intercalated tuffs and reworked tuffs containing abundant water-rounded fragments. There is a further form of volcanic rock, widespread throughout the area, which may best be described as welded tuff. These show a grey or green glassy matrix choked with pyroclastic fragments and are trachytic in composition. They differ from loosely consolidated tuffs in being impervious and their effect on groundwater conditions is similar to that of trachyte lava flows.

The sediments, which can invariably be detected in borehole samples, from the presence of water-rounded fragments, grade from the reworked tuffs mentioned above to lacustrine deposits, which show more complete rounding of the particles in the

coarser layers. It is impossible to distinguish, in samples from percussion boreholes, between reworked tuffs and the lacustrine sediments as both show characteristic buff or yellow colouration and evidence of water transport in the rounding of the detrital fragments. In the sections such light-coloured sedimentary deposits are considered together and given symbols L, Ln, Le, etc., for the reason that during the early part of the survey in the Lake Nakuru basin all such formations were identified as lake beds.

Sikes considered that old land surfaces between the lava flows provided the main aquifers within the volcanic formations. Whilst this type of aquifer undoubtedly occurs, it is now known that the principal aquifers are sediments extending to several hundred feet in thickness, rather than very limited weathered zones forming old land surfaces between an otherwise unrelieved series of lava flows. Sedimentary formations deposited in the lake basins since the cessation of the major faulting in the Rift Valley similarly provide ideal aquifers. They are mainly composed of well-rounded volcanic grits and diatomites, together with red clays.

The types of aquifer are:—

- (i) Sedimentary intercalations in the faulted lava flows.
- (ii) Old land surfaces separating lava flows.
- (iii) Fissures within the body of the lava flows and welded tuff formations.
- (iv) Lacustrine sediments deposited subsequent to the major faulting.

These will now be described in some detail.

Sedimentary Intercalations

The analysis of drilling results given in Appendix A reveals that these comprise about 90 per cent of the aquifers. The volcanic grit horizons form ideal media through which water can flow, whilst the clay horizons provide impervious aquicludes preventing the water sinking to deeper levels. It is not uncommon to find several water-tables within a single thickness of sediments separated by impervious clay layers. The base of a succession of sediments immediately above the top surface of a lava flow is the most common position of a water-table, though the water is frequently struck a few feet down into the body of the flow, since the tops of the trachytic flows are usually scoriaceous, broken up and weathered.

Old Land Surfaces

Water-tables in restricted weathered zones separating flows are not uncommon. Reddened samples devoid of water-rounded fragments, and restricted to a very few feet, usually indicate such aquifers, but such reddening is also found in fissures.

Fissure Supplies

The lava flows are essentially impervious and no water can pass through the main body of the rock. Though the top lay is often scoracious and broken up, allowing water to pass through, completely permeable flows are unknown, the lower part of the flow being invariably massive and impervious in texture. The extensive faulting and fissuring in the Rift Valley provides fissured aquifers within the main body of the flows, but such aquifers are of limited occurrence since the fissures are usually widely spaced and steeply inclined. Thus deliberately siting a borehole to penetrate a fissure is not a practical possibility.

It is a general condition that fissures are more abundant on the downthrow side of the faults, since the downthrown block has moved relative to the upthrow block and is more likely to be fractured. Sections exposed in the recently constructed Rongai tunnel on the Mau scarp reveal that extensive fissuring also occurs on the upthrow side of the faults but the fissures (cutting yellow tuff), though yielding adequate supplies, are widely spaced and the difficulty of locating them by any means

from the surface is manifest. In this case the fault planes and fissures immediately adjacent to the fault zone are infilled with clay and yield no water at all. This condition may account for a few surprising failures of boreholes immediately on fault planes, of which C.1001 on Ronda Sisal Estate is an example.

Lacustrine Sediments of More Recent Age than the Main Faulting

There are many boreholes in the Elmenteita and Nakuru areas obtaining very abundant supplies from these recent lake beds, which have been the subject of extensive investigations by Leakey and Nilsson. The conditions of occurrence are exactly similar to the earlier sedimentary formations. The thick sedimentary formations of the Rongai area are apparently lake beds of comparatively recent age, since they contain intercalations of diatomite. The Rongai plain was probably a lake basin; the lake beds are now completely obscured by a mantle of pyroclastics, black ash and pumice from Menengai.

CHAPTER XII—GROUNDWATER CONDITIONS

The Sections A-A, B-B and C-C illustrate the groundwater conditions in the area. It is clear from these sections that there is a hydrostatic connexion between the underground water bodies throughout the greater part of the area. The hydrostatic level does not usually vary when a second aquifer is struck in a borehole. This indicates a connexion between successive aquifers in depth. In thick sequences of sedimentary rocks, water is usually encountered a few feet above the junction with underlying impervious lava. This suggests that the water bodies consist of shallow layers of water flowing slowly over the impermeable lava surface. Conditions of complete saturation of the permeable aquifer are uncommon.

Perched Water-tables

Perched water-tables are mostly encountered on the high ground above or upon steep scarp slopes. At Kabazi a perched water-table near the surface was encountered in two boreholes, while in others the rest level was much lower, the first water being absent. At Njoro a perched water-table yielding very considerable supplies occurs in the vicinity of the Njoro River. The supply of this aquifer is believed to be derived from seepages down faults in the Njoro River bed. Measurements of losses in the Njoro River reveal that the river loses great quantities of water in the stretches in which very high yields from the perched water-table have been obtained. For instance the loss between Egerton School and the Plant Breeding Station are negligible, and boreholes in the vicinity have very low yields. Between the Plant Breeding Station and the Ngata intake pump, where the river turns along a course parallel to the major fault zone a loss of one cusec has been recorded. Two boreholes here yielded more than 2,500 gallons per hour from the perched water-table.

The yields in the vicinity of the river are exceedingly variable, and it has been found that the best yields are obtained close to fault zones crossing the river. One borehole (C.1362) failed to encounter this perched water-table—though sited but 300 yards from the river. Water was not struck until a depth of 600 feet had been reached and the rest level at 575 feet represents the main hydrostatic surface in this area. The failure of C.1089 is attributed to the fact that there is no perched water-table here and the main piezometric surface is too deep for water to be encountered even in an 800-ft. deep borehole.

The conditions along the Elburgon-Njoro scarp are extremely variable and there appears to be a series of perched water-tables, fed by seepages along faults crossing the river beds. In places where the perched water-table is absent, boreholes may have to be drilled to 600 feet and more (in one case over 900) to strike the main water body which is in hydrostatic connexion with the groundwater underlying the Rongai plain.

Groundwater ridges are commonly built up beneath influent streams. At Nakuru Industries a very abrupt rise in the hydrostatic contours is attributed to a large addition to the groundwater from the Ngosur River which sinks underground immediately to the north. This forms a groundwater ridge raising the water-table above the level of Lake Nakuru in the north-east corner. This feature is responsible for the permanent supply to the hippo pools. Another groundwater ridge is present near the Njoro River at Ronda Sisal Estate where C.307 has a rest level 30 feet higher than C.306 drilled at the same time.

A perched water-table north of Elmenteita Station is probably due to seepage from the Nderit River. Elsewhere in the lake basins there is a close correspondence between the hydrostatic level and the levels of Lakes Nakuru and Elmenteita.

The flattening of the hydraulic gradient near Rongai is very marked. In one borehole (C.1461) the water rises to within 20 feet of the surface. There is a groundwater ridge in the vicinity of the Rongai and Molo Rivers, apparently due to seepage from these rivers into a layer of coarse gravel.

The Relation of Faulting to Groundwater Conditions

That the area is intensely faulted is seen from a glance at the geological map (Map No. 1). In the Rongai district and the Nakuru-Elmenteita basin the faults are obscured by later pyroclastics or lake sediments, but still exist beneath this cover. The faults are open fracture zones, normally devoid of impervious clay filling. They thus act principally as conduits rather than as barriers. The aquifers within the older faulted formations—sedimentary intercalations and the old land surfaces—are displaced by these faults. This forms an irregular series of enclosed flat-lying aquifers, coupled by faults which form the connecting links joining them up into one hydrostatic system. The fault which forms the outlet of one aquifer itself provides the inlet to the next aquifer. This system does not favour artesian conditions, the aquicludes being disrupted at intervals in the fault zones and the water body being rarely completely confined. Sub-artesian conditions are, however, widespread. Artesian water has only been obtained in one borehole in this part of the Rift Valley at Elburgon. This is situated on a major escarpment and can be attributed to the land surface having been locally eroded below the piezometric surface. (See Fig. 10.)

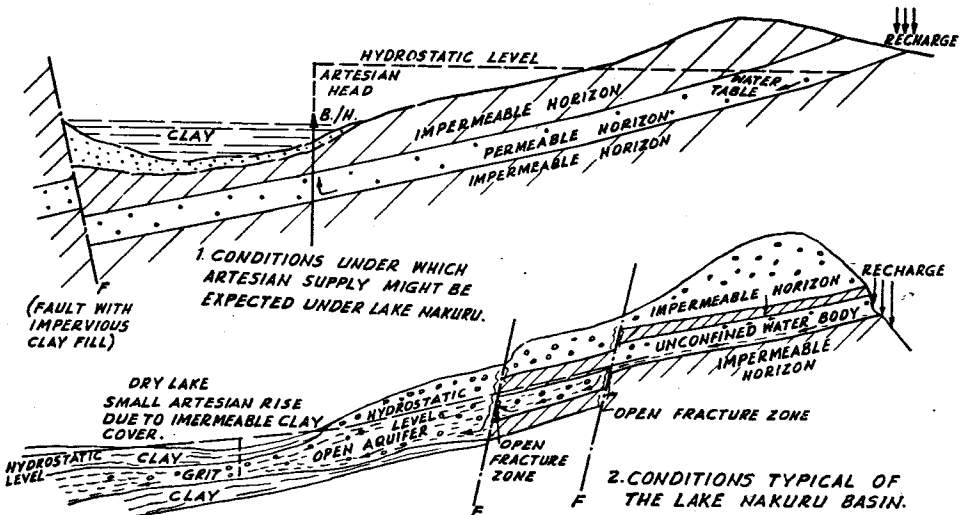


Fig. 10.—Comparison of a confined aquifer producing artesian conditions and the open system of aquifers typical of the floor of the Rift Valley.

The Cause of Borehole Failures

The most common cause of unproductive boreholes in the area is the great depth of the piezometric surface. Besides the borehole (C.1089) already referred to, a large area near Kampi-ya-Moto and McCall's Sidings has failed to produce one drop of water from a borehole. It is considered that the area bounded by Menengai Station, Kampi-ya-Moto Station, McCall's Sidings, Ol Punyata Station and P. E. L. Howard's borehole (C.2006) is one of very deep hydrostatic conditions. In a few cases it is possible that drilling to 1,000 feet might produce water, but in the greater part even that would be of no avail. Further, no appreciable sub-artesian rise can be expected from any very deep supply obtained. The vicinity of the Menengai crater has long been considered to be hopeless as far as groundwater is concerned. But recently several boreholes have been drilled with success close to the rim. C.1847 but 1,500 yards from the rim was observed to yield more than 3,000 gallons per hour and C.2006 yielding 1,800 gallons per hour is scarcely more than a mile away. C.1807 was drilled on a subsided block of the caldera wall, virtually within the limits of the caldera, and produced a large yield at less than 350 feet. It is the opinion of the writer that the greater part of the caldera is underlain by a water-table, there being no evidence of any discontinuity near to the crater, but due to fissuring and broken topography drilling within the crater is not likely to be practicable. A large area of high ground on the northern and western slopes of the volcano is unfavourable for drilling since the predicted hydrostatic level is too deep for water to be struck within reasonably economic depth limits.

In the immediate vicinity of the caldera rim, drilling is rendered difficult or impossible by the presence of numerous fissures—C.1917, A and B, were abandoned for this reason, though it is believed that had it been mechanically feasible to drill to a greater depth water would eventually have been struck, possibly at a depth beyond the practical limits. The conclusions reached as to the effect of the thermal zone of Menengai volcano on the groundwater conditions is discussed below in a separate section dealing with steam conditions in general.

High Temperature Conditions and Groundwater

High temperature conditions are of very common occurrence in the Nakuru area. Boreholes situated along the major fault scarps in particular often yield hot water and hot springs exist at several places along the Subukia-Bahati scarp. The relation between thermal conditions and faulting is explained by the fact that hot juvenile gases rise from the deeper zone of the crust through the openings provided by fault zones and mingle with the groundwater heating it up to considerable temperatures C.991 and C.501 near the Mau scarp, C.855, C.1674 and C.785 are examples of very hot boreholes sited close to major scarps.

Steam conditions occur in Menengai crater itself where many rather weak stream fumaroles issue from the surface. Boreholes C.1066 and 131 encountered steam at 200 feet, south of Ol Punyata Station. The recent Menengai volcanic activity appears to be related to a north-south zone of instability, and these two boreholes are situated on the direct continuation of this line. The extent of the steam conditions near Ol Punyata is a matter of conjecture. It is probable that they are localized to the immediate vicinity of faults. The extreme localization of thermal conditions is illustrated by the fact that at Tindaress one borehole (C.1674) produced hot water whilst another (C.1675) less than half a mile away yielded cold water. The low pressure at which steam issues suggests that it emanates from heated groundwater rather than directly from juvenile sources. The absence of any mineral content in Rift Valley steam vents is also in favour of a source in heated groundwater.

A second zone of steam conditions occurs at Eburru Station where numerous steam vents are condensed for watering cattle. This occurrence is related to the north-south trending zone of recent basaltic eruption, and it is coincident with north-south

faults on which adjustment has continued up to comparatively recent times. Steam conditions are confined to these localities and are unknown elsewhere in the area. It is clear that such conditions are confined to the vicinity of very recent volcanoes and not widespread throughout the Rift Valley as suggested by Sikes. The Menengai caldera, being a relatively early structure, does not define the limits of present-day steam conditions, and steam conditions are only to be expected near to the recent secondary centres of eruption of this volcano.

CHAPTER XIII—GEOPHYSICAL METHODS OF PROSPECTING FOR WATER

Detailed geological investigations in connexion with groundwater problems were only possible to a limited extent prior to 1951. Sikes [2] made a preliminary survey of the problems based on a geological approach. Between 1940 and 1950, owing to shortage of available staff and a great increase in the demand for the services of geologists of the Hydraulic Branch, a largely geophysical approach was adopted. Attempts were made in the Rongai and Nakuru area to show a relationship between the average apparent resistivity values obtained in depth probes and the degree of saturation of the underlying formation. (Unpublished reports by W. H. Reeve and A. O. Thompson filed at the Hydraulic Branch, P.W.D., Nairobi.) A direct relationship between the average resistivity value and the tested maximum yield of boreholes was also postulated. However, the results of further drilling in the Rongai area failed to bear out those conclusions. Before leaving the Hydraulic Branch Reeve concluded that a geological approach to groundwater problems rather than a purely geophysical one should be attempted as soon as a sufficient staff of geologists was available.

The present study has revealed that the water bodies are of very limited thickness, conditions of general saturation over considerable thicknesses of rock being unknown in the area. Such water bodies are likely to give a negligible direct reflection on a resistivity curve, and might very easily give no reflection at all. A relationship between yields and the average resistivity values is clearly not to be expected under such conditions, or, in fact, under any conditions. The presence of a series of aquifers in hydrostatic connexion throughout the greater part of the area has now been revealed. Failures of boreholes are almost entirely due to a great disparity between the ground level and the piezometric surface.

Direct identification of water bodies by resistivity methods being impossible, the question as to whether indirect methods of prediction are of any value must be considered. These involve the correlation of changes in slope of the resistivity curve with breaks in the underlying formations, likely to provide aquifers. A series of resistivity curves taken on the sites of boreholes in the area are shown in Fig. 11. The great variety in shape and average apparent resistivity values is at once apparent. It is seen that similar curves have produced abundant yields in one case, and not a drop of water in another. A comparison with detailed geological sections reveals that there is little or no agreement between changes on the curves and breaks in the geological formation. It is the opinion of the writer that indirect methods of prediction are of no practical use in volcanic formations, disrupted by a complex series of faults of varying age. To use indirect geophysical methods something must be known of the succession before predictions can be made. In relatively unfaulted stratified rocks extrapolations between known successions can be made with confidence. In the Rift Valley it is not possible to do so.

It has never been claimed by geophysicists that resistivity methods are applicable to such complex structures and discontinuous formations as are seen in the Rift Valley. It must be concluded that the use of resistivity methods in this area will never yield information of any value.

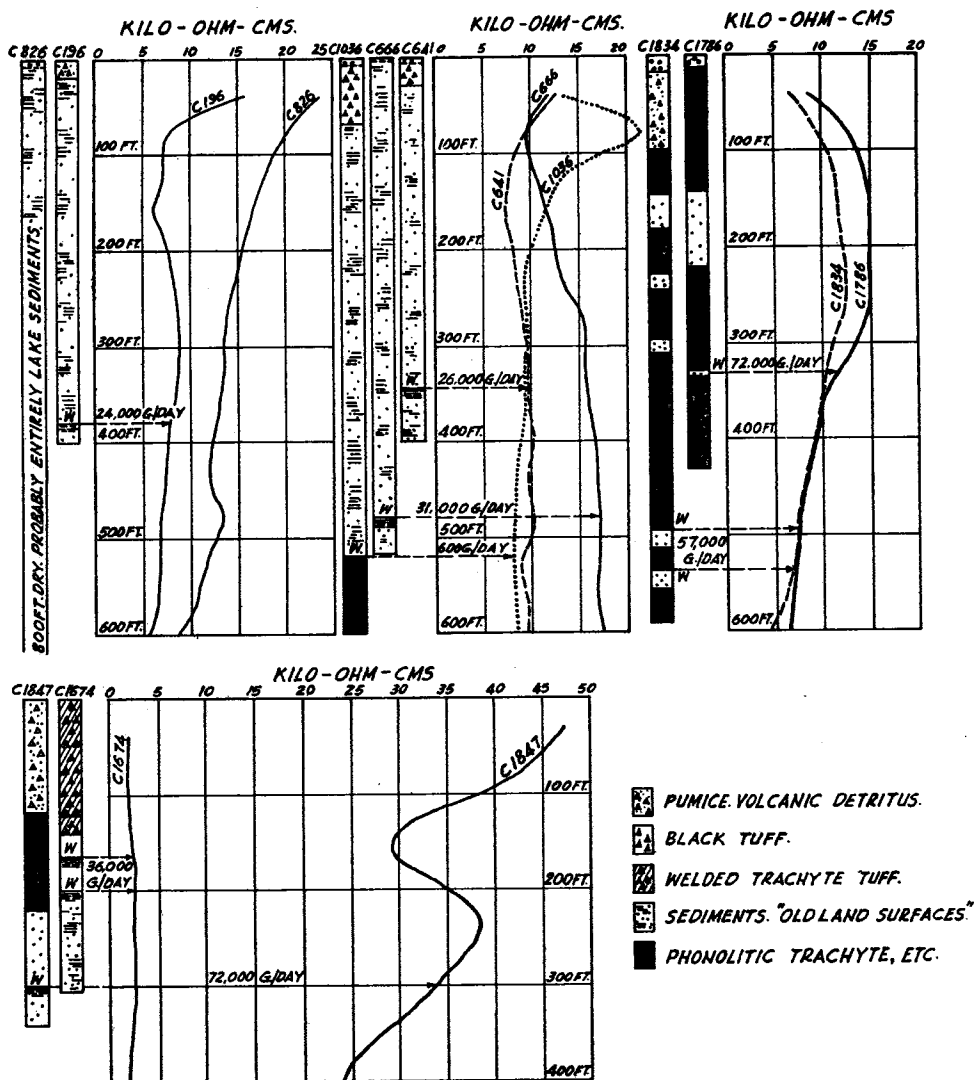


Fig. 11.—Comparison of resistivity curves in boreholes drilled in the Nakuru area showing lack of correlation between depth probes of similar type and results obtained by drilling.

CHAPTER XIV—SODA DUST FROM LAKE NAKURU

Of economic significance to the district is the nuisance at present being caused by the removal of soda dust from the dry surface of Lake Nakuru—to be blown in murky clouds over the town and surrounding country. The incidence of fluorosis in children is well known and the high fluoride content of this dust suggests that it could have a considerable toxic effect on human beings, livestock and growing crops, although this has not been convincingly established.

The hydrological aspect of this problem has been under investigation and a report issued (F. Grundy [13]). A brief description of the groundwater aspects is given here.

Lake Nakuru is a shallow pan in the centre of a drainage basin of some 450 square miles. The recharge of the lake and underlying aquifers is partly from intermittent surface streams—the Njoro, Lamudiac, Makalia and Nderit rivers—together with directly absorbed rainfall; and partly by subterranean recharge from the water-table. The hydrostatic contours fall towards the lake, indicating a steady flow of groundwater into the centre of the basin, and the absence of any subterranean outlet north or south of the lake.

The lake is at present in the ultimate stage of its existence. In the present climatic cycle the lakes of East Africa are gradually receding and drying up. Lake Rudolf is regressing to a marked degree, and Lake Solai has completely dried up. Lake Nakuru itself has reached a state of frequent alternation between complete dryness and a shallow expanse of water.

The most recent sediments deposited in the lake consist of a fine compact, silty clay which is comparatively impervious allowing water to pass through but slowly. The recharge from the surrounding country reaches the lake area and passes under this clay layer through earlier deposited and more pervious sediments. It rises slowly through the clay by capillarity and is evaporated from the surface, leaving behind an encrustation of soda crystals derived from the saline constituents of the groundwater. It is this crust of soda which is caught up by the wind and blown up into dust clouds. The artesian pressure under the lake is small. Not more than 4 ft. of artesian head has been recorded. It is attributed to the relatively impervious clay layer which confines the water under the lake in an extensive enclosed aquifer. Owing to the flat nature of the terrain and the absence of any enclosing acquiclude beyond the limits of the lake, the artesian head is negligible.

The periodical filling of the lake after rain seldom extends to more than a few inches above the clay surface and probably depends entirely upon increments of surface water. In very wet years, however, the lake fills up to a depth of 5 ft. In 1951–1952 it remained full for a period of 18 months. The water cannot sink through the saturated clay, consequently, it remains until evaporated, leaving once again a dry, dusty surface. Local opinion favours the idea of keeping part of the lake full by artificial means. In this choice it relies on the local belief that “great quantities of artesian water must exist beneath the lake”. This is a fallacy based on an inability to distinguish between confined aquifers and open systems.

The conditions whereby such an artesian supply could be found are illustrated in Fig. 10. The first drawing shows a continuous confined aquifer inclined in such a way as to produce an artesian head. The second drawing shows the condition of open aquifers and confined aquifers of limited extent broken up by open fault fractures—the condition typical of the Nakuru area. Schemes to concrete the faults in river beds, and other undertakings might produce a little increase in the water supply to the lake, but the chance of obtaining the estimated requirements of about 30 cusecs from artesian supply is infinitesimal. The writer is of the opinion that the ultimate solution to the problem will be found in speeding-up the natural process of reclamation by vegetation rather than by artificial rejuvenation of the lake.

CHAPTER XV—THE NJORO RIVER

Geological Note

The Njoro River follows a zig-zag course from the Egerton School to Glanjoro Farm, alternately following the line of north-south fault zones and cutting eastwards across the area between the fault zones. In the Njoro area the older faulted lavas and tuffs are covered by compact black ash from Menengai, usually about 30 to 50 ft. thick. This black ash, known as building stone, is usually concentrated in the river valleys, and the Njoro River is no exception. The river is cut down through overlying unconsolidated pumice and ash and runs over the hard upper surface of the black ash. This ash has been disrupted by minor faults on the older north-south lines and probably about 8,000 to 10,000 years old.

A study of the groundwater conditions indicates the presence of perched water-tables in the vicinity of the Njoro River. This is attributed to losses down the fault zones. Lower down the Njoro River movements are still proceeding in a fault trough extending from Butleigh Stone Quarry through Glanjoro to Ronda Sisal Estate. Evidence of the present-day adjustments in the Rift Valley is invariably found in fault troughs. In this case surface fissures on Ronda Sisal Estate and the open fissures of Proctor's and David's Faults, down which the Njoro River loses a great deal of the water remaining in it at this point, clearly indicate that tectonic adjustments on a small scale are still proceeding.

The Njoro River tapers completely on reaching the Lake Nakuru plain, firstly, because of these losses in the fissure zones, and secondly because its bed runs over porous pumice and lake sediments and the water sinks to join the water-table which feeds Lake Nakuru.

CHAPTER XVI—THE POSSIBILITY OF UTILIZING STEAM AS A SOURCE OF POWER IN THE RIFT VALLEY

This possibility has recently been suggested by the late Mr. James Scott [8]. The paper referred to is based on very sweeping conclusions about the geology of the Rift Valley, which are not supported by detailed investigations. For instance, Mr. Scott claims that the proportion of pyroclastic rocks to lavas in the Rift Valley exceeds 80 per cent. This is based on a computation of surface exposures. In bulk, lavas greatly predominate on the floor of the Rift Valley, though pyroclastics form a superficial mantle over wide areas. Again, Mr. Scott considers that Menengai volcano is almost entirely composed of pyroclastic material, a conclusion with which the writer, who has examined the caldera in detail, completely disagrees. Mr. Scott's theory of the origin of the Rift Valley due to the weight of the ice on the polar regions during the Pleistocene era is refuted by the geological evidence—the Rift Valley is far older than the Pleistocene glaciation.

Steam under pressure possibly does exist at depth in the Rift Valley, though the broken and faulted nature of the overlying rock would tend to allow a continuous release, and prevent any great pressure being built up. The idea of a fold of Kamasian sediments acting as a cap retaining the steam is not accepted by the writer. These sediments are faulted and broken to a considerable extent, and it is extremely doubtful if such a perfect, continuous structure as visualized by Mr. Scott exists anywhere in the Kenya Rift Valley.

That steam under some pressure may be found by deep drilling is not completely impossible, but three questions should be borne in mind:—

- (i) Whether there is any likelihood of steam being encountered in sufficient volume and under sufficient pressure.*
- (ii) Whether there is a demand for electricity in the vicinity to warrant such an expensive scheme.
- (iii) Whether the engineering problems are surmountable. In the Lardarello Valley (Italy) where a similar scheme has been put into operation, many problems due mainly to corrosion of pipes have been encountered, and considerable funds have to be spent yearly on replacement.

Such problems would be more critical in Kenya, a country in which engineering equipment has to be transported thousands of miles at prohibitive cost.

Three localities in the Nakuru area are possible sources of steam for power projects:—

- (i) Eburru-Elmenteita. (ii) Menengai. (iii) Kamasia.

* A paper by the writer dealing with this problem was read at the XXth International Geological Congress, in 1956, before revision of this report. The writer concludes that the discovery of steam in any quantity and under sufficient pressure is extremely improbable.

REFERENCES

- [1] J. W. Gregory, *The Rift Valleys and Geology of East Africa*, 1921.
- [2] H. L. Sikes, *The Underground Water Resources of Kenya Colony*, 1934.
- [3] R. M. Shackleton, *The Kavirondo Rift Valley*, 1951.
- [4] R. B. McConnell, *Rift and Shield Structure in East Africa*, 1948.
- [5] E. Nilsson, *Quaternary Glaciations and Pluvial Lakes in East Africa*, 1932.
- [6] L. S. B. Leakey and J. D. Solomon, *The Stone Age Cultures of Kenya*, 1931.
- [7] L. S. B. Leakey, *East African Lakes*, 1932.
- [8] J. Scott, *The Great Rift Valley and its Economic Possibilities*, 1953.
- [9] S. M. Cole, *An Outline of the Geology of East Africa*, 1950. (Contains a useful list of references relating to the geology of East Africa.)
- [10] J. le Conte, *On the Origin of Normal Faults and the Structure of the Basin Range Region*, 1889.
- [11] S. J. Shand, *Rift Valley Impressions*, 1936.
- [12] S. J. Shand, *The Rocks of the Kedong Scarp, Kenya Rift Valley*, 1937.
- [13] F. Grundy, *Lake Nakuru*, 1953.
- [14] R. M. Shackleton, *Geology of the Nyeri Area*, 1945.
- [15] R. M. Shackleton, *Pleistocene Movements in the Gregory Rift Valley*, 1955.

ACKNOWLEDGMENTS

The author is indebted to Mr. S. Stock and Mr. M. W. Jowett for final revision of text and illustrations before submission to the Government Printer.

APPENDIX

ANALYSIS OF DRILLING RESULTS

N.B.—The figures contained in this appendix include the drilling results up to the end of April, 1956.

1. NAKURU

Number of boreholes drilled	56
Successful boreholes (over 208 gallons/hour)	54
Average yield in gallons/hour	2,285
Average depth in feet	439
Unsuccessful boreholes	2

(a) C.822—*S. Greensted*

Not drilled deep enough to strike the water-table (probably stopped 50 ft. short).

(b) C.1001—*Ronda Sisal*

Sited on a major fault, fissuring caused loss of drilling water and caving.

2. RONGAI

Number of boreholes drilled	34
Successful boreholes	28
Average yield in gallons/hour	1,212
Average depth in feet	425
Unsuccessful boreholes	6

(a) C.62—*I. W. Whitmore*

This borehole, an early attempt at obtaining groundwater, was stopped only a few feet above the hydrostatic level. It is clear that deepening to about 600 ft. would produce a satisfactory supply.

(b) C.147—*Lord Francis Scott (Deloraine)*(c) C.148—*Lord Francis Scott (Deloraine)*

Shallow boreholes which obtained only a limited supply. A later borehole drilled much deeper in the vicinity (C.1647) obtained a satisfactory supply.

(d) C.322—*Lord Francis Scott (Deloraine)*

This borehole was drilled to 600 ft., below the probable hydrostatic level. It is situated on the lowest spurs of the Mau scarp, in what is undoubtedly a highly faulted zone, and it may be that faulting and fissuring have some bearing on the complete absence of any aquifer.

(e) C.826—*Captain H. Barclay*

The hydrostatic level in the vicinity of this borehole is estimated at about 5,750 ft. above sea level. As the altitude of the borehole is 6,420 ft., water can only be expected below 770 ft. Drilling beyond the existing depth of 800 ft. would probably have produced a satisfactory supply but the rest level of about 770 ft. would have made pumping very costly.

(f) C.2152—*Mrs. H. McKenzie*

3. SOLAI—NORTH MENENGAI

Number of boreholes drilled	44
Successful boreholes	36
Average yield in gallons/hour	1,677
Average depth in feet	436
Unsuccessful boreholes	8

(a) 122—*A. J. Simpson*

Shallow. Further drilling would probably have encountered steam conditions.

(b) 131—*A. J. Simpson*

Steam conditions encountered.

(c) C.257—*Manuel and Keppe*

Tested yield only 2,926 gallons per day. The cause of this failure is obscure. It is suggested that the aquifer might have been sealed off by the puddling effect of the drill, in which case surging might have produce a much higher yield. Alternatively, the low yield compared with that of C.270 some 300 yards downstream, may be due to the fact that the latter may have derived its greater supply by seepage down a well-exposed fault, which traverses the river between the two boreholes.

(d) C.341—*H. F. Ward, Kabazi*(e) C.534—*H. F. Ward, Kabazi*

These boreholes were drilled in a deep fault trough largely infilled with clay; a little water was obtained in C.341, some 900 gallons per day. It is probable that the aquifers encountered in the high yielding boreholes, a few hundred yards to the east, are sealed off by this impermeable clay.

(f) C.1066—*A. J. Simpson*

Steam conditions encountered.

(g) C.1917 (*A and B*)—*J. A. Seys*

Sited within a quarter of a mile of Menengai caldera. Intense fissuring related to the caldera subsidence rendered drilling beyond 300 ft. impossible.

(h) C.2162—*S. O. V. Hodge*

4. KAMPI-YA-MOTO—LOMOLO

Number of boreholes drilled	..	..	..	..	..	13
Successful boreholes	..	..	..	..	..	5
Average yield in gallons/hour	..	..	..	..	..	1,685
Average depth in feet	..	..	..	..	..	525
Unsuccessful boreholes	..	..	..	..	..	8

(a) H.1—*E. G. Thornhill*(b) C.557—*Land Bank*(c) C.591—*E. G. Thornhill*(d) C.615—*E. G. Thornhill*(e) C.642—*J. Stanning*(f) C.680—*W. E. McLean*(g) C.1036—*W. Evans*(h) C.1809—*H. C. J. Hissey*

All due to great depth of the hydrostatic level in the highly fissured and faulted Kampi-ya-Moto-McCall's Sidings area.

Drilling to 800 ft. on the site of C.642 would probably obtain a supply. In the case of the other abortive sites drilling to 1,000 ft. might fail to obtain a supply, and in the event of any very deep aquifer being struck, the rest level would show little or no sub-artesian rise, making pumping costly and difficult in the extreme.

5. ELMENTEITA

Number of boreholes drilled	33
Successful boreholes	29
Average yield in gallons/hour	1,460
Average depth in feet	489
Unsuccessful boreholes	4

(a) C.2288—*Cresswell Ltd.*

Abandoned at 910 ft.

(b) C.2541—*Block Estates Ltd.*

(c) C.2542—*Block Estates Ltd.*

(d) C.2543—*Block Estates Ltd.*

Abandoned owing to drilling difficulties.

6. NJORO (NORTH)

Number of boreholes drilled	8
Successful boreholes	7
Average yield in gallons/hour	1,687
Average depth in feet	521
Unsuccessful boreholes	1

(a) C.1089—*G. B. Farms*

Drilled to 800 ft. Dry. The higher perched water-table was not encountered (? restricted to the vicinity of the Njoro River). The topographical position of this borehole indicates that the main lower water-table might be encountered by drilling on to 900 or 1,000 ft., but there would be little or no sub-artesian rise.

1.—NAKURU

No.	Owner	Tested Yield in Gal./hr.	Depth	Water Struck	REST LEVEL		Altitude	Nature of Aquifer and Remarks
					Below Surface	Reduced Level		
SA.58	Nakuru Industries..	1,800	323	157, 212 ..	220	5,885	6,105	Not known.
C.152	Nakuru Industries..	4,000	223	159-223 ..	159	5,946	6,105	Water laid sediments.
C.204	Nakuru Industries..	3,660	250	185, 200 ..	86	6,011	6,097	Water laid sediments.
C.222	Nakuru Industries..	2,800	298	200-227 ..	170	5,815	6,180	Water laid sediments.
C.287	C. J. E. David (Glanjoro)	1,350	450	420 ..	365	5,815	6,180	Base of water laid sediments at contact with underlying phonolitic trachyte lava flows. F=1.56 p.p.m.
C.306	Ronda Sisal Ltd. ..	3,000	240	60-220, 238 ..	62	5,778	5,840	Water laid sediments deposited by earlier and more extensive Lake Nakuru; water saline.
C.307	Ronda Sisal Ltd. ..	2,300	230	43 ..	43	5,820	5,860	Water laid sediments deposited by earlier and more extensive Lake Nakuru; water saline.
C.316D	J. A. McDonald ..	1,870	441	120, 190, 280, 430	254	5,911	6,165	Not known.
C321	J. A. McDonald ..	3,000	322	225, 312 ..	220	5,900	6,120	Thick sequence of water laid sediments.
C408	Nakuru Industries..	1,250	439	241 ..	?	6,105	6,470	Not known.
C419	D. W. Molony ..	1,050	500	523, 600 ..	518	5,952	6,470	1st. Base of several hundred feet of water laid sediments intercalated in phonolitic trachyte flows.
C670	D. Naylan ..	4,000 +	370	210, 330-360 ..	170	5,900	6,070	2nd. Grit horizon. Water very cold.
C719	J. A. McDonald ..	2,000	502	225, 450 ..	213	5,909	6,122	1st. A sedimentary horizon underlying a lava flow
C732	Nakuru Municipality	2,000	500	220, 450 ..	199	5,954	6,153	2nd. In a phonolitic trachyte flow.
C805	P.W.D. Road Construction	1,800	546	370, 447, 527 ..	374	5,779	6,153	Thick sequence of water laid sediments.
C813	S. Greenstead ..	2,100	501	480 ..	398	5,837	6,235	Thick sequence of water laid sediments with impervious clay horizon below aquifer.
C822	S. Greenstead ..	Nil	453	— ..	—	—	6,283	Water laid sediments intercalated in phonolitic trachyte lava flows; water very hot.
C836	H. F. Webb ..	1,000	567	533 ..	227	5,958	6,185	Not known.
C855	Lord Egerton of Tatton	1,000	623	604 ..	598	5,822	6,420	Thick sequence of water laid sediments.
C858	Lady Claud Hamilton (Nderit)	2,500	494	448, 470 ..	380	5,794	6,174	Water laid sediments intercalated in lava flows; hot water.
C869	F. C. Davies ..	850	450	435 ..	429	5,802	6,231	Water in old land surface separating phonolitic trachyte flows.
C882	G. J. Turner ..	1,200	593	530 ..	526	5,824	6,350	In lake sediments above lava.
C950	Nakuru Lake Syndicate	1,500	167	5 ..	5	5,775	5,780	Water laid sediments below lava flow.
C993	C. D. Hill (Glanjoro)	960	426	380, 408 ..	370	5,930	6,300	Recent soda lake evaporite deposits; seepage from Lake Nakuru. Extremely saline.
C1001	Ronda Sisal Ltd. ..	Nil	800	— ..	—	—	6,350	Thin water laid sediment horizon intercalated between two phonolitic trachyte lava flows.
C1022	Ronda Sisal Ltd. ..	1,870	416	270, 330-370 ..	265	5,820	6,085	Drilled on a fault zone—repeated fissuring caused loss of drilling water.
								Two aquifers in water laid sediments (grits) overlying impermeable clay horizons.

No.	Owner	Tested Yield in Gal./hr.	Depth	Water Struck	REST LEVEL		Altitude	Nature of Aquifer and Remarks
					Below Surface	Reduced Level		
C1028	F. H. Narraway ..	1,460	750	570, 730 ..	549	5,801	6,350	At the base of an extensive sedimentary sequence separating phonolitic trachyte flows, and in a lower sedimentary horizon. Hot water.
C1080	Lady Claud Hamilton (Nderit) ..	1,870	525	360, 485 ..	351	5,834	6,185	Old land surface separating phonolitic trachyte (?) flows.
C1082	E. A. P & L. Co. ..	3,340	363	215, 280, 330, 350	197	5,962	6,159	Thick sequence of water laid sediments; impervious clay horizon below aquifer.
C1190	Ronda Sisal Ltd. ..	2,000	565	100, 550 ..	299	5,779	6,078	In thick sequence of water laid sediments overlying lavas in Larmudiac River valley.
C1246	R.A.S.K. Show Ground ..	2,000	420	380 ..	359	5,778	6,137	Water laid sediments below a phonolitic trachyte lava flow. Water appreciably saline. F=30 p.p.m.
C1374	J. Molvig ..	6,000	345	220, 335 ..	200	5,959	6,159	A thick sequence of water laid sediments above an impervious clay horizon.
C1389	J. A. McDonald ..	1,000	540	150, 495 ..	134	6,066	6,200	A thick sequence of water laid sediments.
C1434	A. J. Ulyate ..	1,300	450	120, 240, 410	120	6,255	6,375	A thick sequence of water laid sediments (volcanic grits).
C1436D	E. Collier ..	3,000	467	148, 380, 410	60	6,430	6,490	Not known.
C1489	Mrs. Boyer ..	3,300	176	120 ..	98	5,792	5,890	In water laid sediments deposited in an earlier more extensive Lake Nakuru. Water appreciably saline. F=35 p.p.m.
C1490	Ronda Sisal Ltd. ..	4,100	185	80 ..	62	5,778	5,840	In water laid sediments deposited in an earlier more extensive Lake Nakuru. Water appreciably saline. F=35 p.p.m. (Within 10 yds. of C306). Water
C.1535	G. J. Turner ..	1,100	620	585 ..	580	5,800	6,380	Water laid sediments between lava flows. Very hot water (110 deg. F.).
C1558	J. A. McDonald ..	2,000	443	425 ..	404	5,814	6,218	Water laid sediments underlying a phonolitic trachyte lava flow.
C1665	W. Jenkins ..	1,900	352	335 ..	261	5,831	6,092	In a sedimentary (volcanic grit) horizon separating lava flows.
C1666	J. Molvig ..	3,600	615	365, 575 ..	209	5,966	6,175	A thick series of water laid sediments above an impermeable clay horizon. F=6.7 p.p.m.
C1763	Nakuru Municipality ..	5,000	422	320 ..	300	5,760	6,060	One or more old land surface deposits, phonolitic trachyte lava flows. F=4.8 p.p.m.
C1805	Nakuru Municipality ..	4,800	427	312-400 ..	300	5,781	6,081	Thick sedimentary sequence (water laid grits and clays).
C1847	W. Prentice ..	3,000	339	300 ..	300	6,160	6,460	In a sequence of water laid volcanic grits underlying the Menengai lavas.
C2128	E.A.T.C. ..	3,600	443	120-443 ..	106	—	—	Drilled subsequently to original report.
C2129	E.A.T.C. ..	1,300	600	300-600 ..	160	—	—	Drilled subsequently to original report.

No.	Owner	Tested Yield in Gal./ hr.	Depth	Water Struck	REST LEVEL		Altitude	Nature of Aquifer and Remarks
					Below Surface	Reduced Level		
C2140	J. T. Oberholzer ..	2,400	370	350	313			Drilled subsequently to original report.
C2269	E.A.P. & L. (Lanet) ..	2,250	492	220, 350, 370, 435	200			Drilled subsequently to original report.
C2278	R.A.S.K. (No. 2) ..	2,400	405	346	335			Drilled subsequently to original report.
C2393	Maj. W. E. Farr ..	3,000	440	340-420 ..	310			Drilled subsequently to original report.
C2394	K. Barton-Ireland ..	3,000	385	280	243			Drilled subsequently to original report.
C2397	K. Barton-Ireland ..	3,000	510	310, 400 ..	290			Drilled subsequently to original report.
C2402	J. A. McDonald ..	3,000	325	260, 300 ..	220			Drilled subsequently to original report.
C2409D	Engorslunda Farm ..	2,800	590	260, 380, 445?, 570?, 560-590.	322			Drilled subsequently to original report.
C2445	D. H. M. Dempster ..	600	800	357, 780 ..	256			Drilled subsequently to original report.
C2493	H. B. Barclay ..	2,000	482	345, 455 ..	308			Drilled subsequently to original report.
2.—RONGAI								
C62	I. W. Whitmore ..	Nil	466	—	—		6,480	Not known.
C63D	Lord Francis Scott (Deloraine) ..	250	350	343	?		6,550	Water laid sediments—volcanic grits and clays.
C147	Lord Francis Scott (Deloraine) ..	155	318	160, 233 ..	69		6,400	Not known.
C148	Lord Francis Scott (Deloraine) ..	90	254	?	88		6,450	Thick sequence of sediments, volcanic grits and clays.
C196	H. H. Kjaerting ..	1,000	400	380	205		6,200	Thick sequence of sediments, volcanic grits and clays.
C293	O. B. Hewson ..	900	415	390 ..	375		6,150	Thick sequence of sediments, volcanic grits and clays.
C322	Lord Francis Scott ..	Nil	600	—	—		6,900	Thick series of water laid sediments, volcanic grits and clays. Hot water (106 deg. F.).
C501	A. F. Dudgeon (Gogar) ..	650	350	265 ..	221		6,370	Three aquifers: 1st in sediments at contact with underlying phonolite; 2nd in phonolite (Fissure supply or old land surface); 3rd in a lower sedimentary grit horizon.
C516	A. F. Dudgeon (Gogar) ..	900	630	410, 550, 615 ..	338		6,920	Not known.
C541	Lord Francis Scott ..	620	400	280, 300, 317, 332, 365.	223		6,350	Water laid sediments, volcanic grits and clays; one aquifer immediately above an impervious diatomitic clay horizon.
C641	I. W. Whitmore ..	1,100	406	345, 397 ..	337		6,000	Thick sequence of sediments, volcanic grits and clays.
C666	Mrs. Birkbeck ..	1,300	518	480-500 ..	430		6,130	Thick sequence of sediments, volcanic grits and clays.
C799	P. W. D. Road Construction ..	1,300	551	92-195 ..	82		6,320	Thick sequence of sediments, volcanic grits and clays. (Above contact with underlying impervious phonolitic (?) lava.)
C802	P. W. D. Road Construction ..	2,000	360	264 ..	212		6,380	Thick sequence of sediments, volcanic grits and clays. (Above contact with underlying impervious phonolitic (?) lava.)

No.	Owner	Tested Yield in Gal./hr.	Depth	Water Struck	REST LEVEL		Altitude	Nature of Aquifer and Remarks
					Below Surface	Reduced Level		
C803	P.W.D. Road Construction	1,300	599	527	510	6,110	6,620	Thick sequence of sediments, volcanic grits and clays. (Above contact with underlying impervious phonolite (?) lava.)
C826	Capt. H. Barclay	Nil	800	—	—	—	6,420	Thick sequence of water laid sediments, volcanic grits and clays.
C827	Mrs. Lomax	1,300	250	130-204	109	6,191	6,300	Water laid sediments—volcanic grits and clays
C985	I. W. Whitmore	600	495	481	475	5,995	6,470	Intercalated in phonolite.
C991	A. F. Dudgeon (Gogar)	900	397	120, 280	135	6,130	6,265	Thick series of water laid sediments, volcanic grits and clays below phonolite. F=3.3 p.p.m.
C1040	I. W. Whitmore	1,800	442	400-425	392	5,678	6,070	Water laid sediments, volcanic grits and clays. F=3.3 p.p.m.
C1296	H. Stjernsward	2,100	310	90, 255, 280	62	6,108	6,170	Water laid sediments, volcanic grits and clays at contact with underlying lava. F=6.7 p.p.m.
C1314	H. H. Kjaerting	2,200	500	395-445, 470-485	360	5,855	5,215	Thick sequence of sediments, volcanic grits and clays.
C1334	Ruben Bros.	2,100	410	120, 390	70	6,150	6,220	Thick sequence of sediments, volcanic grits and clays at contact with underlying lava.
C1460	A. F. Dudgeon	2,400	218	52, 166	20	6,190	6,210	Thick sequence of sediments, volcanic grits and clays. F=5.4 p.p.m.
C1461	A. F. Dudgeon	2,000	196	120, 180	38	6,172	6,210	Thick sequence of sediments, volcanic grits and clays. F=5.4 p.p.m.
C1462	Hon. A. Pritam	2,400	200	41, 180	38	6,112	6,150	Thick sequence of sediments, volcanic grits and clays. F=5.6 p.p.m.
C1463	Rongai Township	2,100	365	68, 150, 330	45	6,115	6,160	Thick sequence of sediments, volcanic grits and clays at contact with underlying lava. F=5.75 p.p.m.
C1647	Lord Francis Scott (Deloraine)	1,000	717	167, 421, 680	120	6,190	6,310	Three aquifers: 1st in thick sequence of water laid sediments; 2nd immediately above contact with underlying impervious phonolite (?); 3rd in sedimentary grits intercalated between phonolite lava flows.
C1750	J. Evans	3,000	361	275, 335-350	241	5,839	6,080	Thick sequence of water laid sediments volcanic grits and clays at contact with underlying lava.
C1867	G. J. Grant	1,000	633	570-590	518	6,832	7,350	At base of sedimentary sequence, above contact with phonolite.
C1869	F. A. Harris	750	410	320-410	210	6,210	6,420	Sedimentary sequence, volcanic grits and clays.
C2152	Mrs. H. McKenzie	Nil	660	—	—	—	—	Not known.
C2346	Rongai Workshop	1,000	202	70, 140, 180	46	—	—	Sedimentary sequence, volcanic grits and clays (B.H. originally known as H2 before re-drilling).
C2563	G. Eccles	3,000	284	160	67	6,198	6,265	

3.—SOLAI—NORTH MENENGAJ

No.	Owner	Tested Yield in Gal./ hr.	Depth	Water Struck	REST LEVEL		Altitude	Nature of Aquifer and Remarks
					Below Surface	Reduced Level		
122	A. J. Simpson	Nil	146	—	—	—	5,530	Steam conditions (low pressure).
131	A. J. Simpson	Nil	274	—	—	—	5,550	Water rounded sediments intercalated in lava.
C257	Manuel & Keppe	120	465	120-185	98	5,582	5,680	No samples.
C270	Manuel & Keppe	1,350	150	85	98	5,446	5,510	Deep clay fill in fault trough.
C341	H. F. Ward (Kabazi)	40	574	270	100	7,190	7,290	Sedimentary intercalations in phonolitic and basalt lavas.
C345	H. F. Ward (Kabazi)	2,500	274	265	190	7,192	7,382	No samples.
C534	H. F. Ward (Kabazi)	Nil	440	—	—	—	7,290	Sedimentary intercalations in phonolitic and basalt lava.
C566	H. F. Ward (Kabazi)	3,000	290	90, 290	240	7,190	7,430	Sedimentary intercalations in phonolitic and basalt lava.
C736	H. F. Ward (Kabazi)	5,400	365	78, 110, 194-217, 326, 353.	32	7,518	7,550	Sedimentary intercalations in phonolitic and basalt lava. Perched water table.
C737	H. F. Ward (Kabazi)	2,700	320	69, 95, 133, 168, 311-315.	56	7,374	7,430	Sedimentary intercalations in phonolitic and basalt lava. Perched water table.
C1066	A. J. Simpson	Nil	593	—	—	—	5,700	Steam conditions (low pressure).
C1674	Tindaress Ltd.	2,900	304	165, 200	138	6,137	6,275	Water rounded sediments.
C1675	A. F. MacCalman	2,600	304	290	67	6,153	6,220	Water rounded sediments.
C1743	C. Mowbray Brown	2,000	314	300	148	5,707	5,855	In lava (basalt ?); fissure supply.
C1744	G. B. Ireland	1,000	340	320	140	6,330	6,470	In water rounded sedimentary formation below lava.
C1745	G. B. Ireland	1,800	475	290, 430	200	6,030	6,230	1st in weathered lava beneath a thick series of sediments; 2nd in volcanic sediments.
C1746	G. B. Ireland	1,200	475	230, 465	295	5,645	5,940	Water rounded sediments intercalated in lava flows.
C1760	Mrs. Hawkins (Glencairn)	2,400	384	300, 345	180	6,220	6,400	Water rounded sediments intercalated in lava flows.
C1765	H. H. Peet	240	528	500	460	5,640	6,100	Water rounded sediments intercalated in phonolitic trachyte (?) lava flows. Tool lost in hole, purely a drilling failure.
C1766	H. H. Peet	2,000	500	490	180	5,970	6,150	In water rounded sediments.
C1779	F. H. Baillie	2,100	364	180, 220, 325	160	6,040	6,200	1st and 2nd aquifers in water rounded sediments; 3rd in lava (?) fissure supply or old land surface.
C1786	B. R. MacKenzie	3,000	430	330	330	5,195	5,525	In lava flow (probably old land surface or fissure supply). Samples seen at B.H. site showed some reddening at 330 ft.
C1807	J. A. Seys	1,500	375	250, 350	219	5,761	5,980	In volcanic sediments—below Menengai lavas.
C1818	J. W. Eames	3,000	600	500	471	5,430	5,901	Not known.
C1834	C. Horn (Banita Sisal)	2,300	590	494, 535	433	5,017	5,450	In old land surface separating lavas (?) phonolitic and basalt.
C1837	K. E. & R. H. Adams	3,000	600	515	515	5,366	5,881	In volcanic sediments intercalated between lava flows.
C1909	C. Horn (Banita Sisal)	1,200	700	665	435	5,015	5,450	No samples.
C1917	J. A. Seys	(a) Nil (b) Nil	334 212	—	—	—	6,150	Intense fissuring encountered. Site within ½ mile of caldera rim.

3.—SOLAI—NORTH MENENGAI—(Cont.)

No.	Owner	Tested Yield in Gal./hr.	Depth	Water Struck	REST LEVEL		Altitude	Nature of Aquifer and Remarks
					Below Surface	Reduced Level		
C1944	C. Horn	1,200	800	385, 650	280	5,170	5,450	No samples.
C1946	Banks Estate	1,700	516	483	483	5,599	6,082	Old land surface.
C1954	C. Mowbray Brown	1,250	377	100, 275	84	5,926	6,010	1st old land surface. 2nd ? fissure in lava.
C2006	P. E. L. Howard	1,800	780	727	722	5,328	6,050	In water laid sediments on old land surface.
C2122	Capt. W. A. Harries	800	700	578, 588	556	—	—	Drilled subsequently to original report.
C2131	G. Ireland	3,000	463	300, 453	94	—	—	Drilled subsequently to original report.
C2162	S. O. V. Hodge	70	500	175	100	—	—	Drilled subsequently to original report.
C2164	W. C. Holmes	2,800	383	200-383	75	5,557	6,097	Drilled subsequently to original report.
C2184	J. W. F. S. Day	3,000	562	540	540	5,993	6,273	Drilled subsequently to original report.
C2216	F. H. Clarke	500	500	440-500	280	—	—	Drilled subsequently to original report.
C2272	W. A. C. Allison	2,400	189	110, 189	55	—	—	Drilled subsequently to original report.
C2282	G. C. Gabbert	1,200	500	300-480	124	—	—	Drilled subsequently to original report.
C2283	C. O. Powis	1,800	330	180, 320	156	—	—	Drilled subsequently to original report.
C2309	P. Steyn	1,800	490	350-450	285	—	—	Drilled subsequently to original report.
C2398	B. J. Holmes	2,200	247	150→	100	—	—	Drilled subsequently to original report.
C2484	Kisinana	900	400	365	335	—	—	Drilled subsequently to original report.

4.—KAMPI-YA-MOTO—LOMOLO

KAMPI-YA-MOTO

H1	E. G. Thornhill	Nil	370	—	—	—	5,850	
C557	Land and Agricultural Bank	Nil	650	—	—	—	5,725	
C391	E. G. Thornhill	Nil	270	—	—	—	5,880	
C615	E. G. Thornhill	Nil	820	—	—	—	5,840	
C680	W. E. McClean	Nil	602	—	—	—	5,700	
C1036	W. Evans	Nil	610	—	—	—	5,900	
C1809	H. C. J. Hissey	Nil	608	—	—	—	5,883	

LOMOLO

C642	J. Stanning	Nil	550	—	—	—	5,300	Apparently in phonolite—fissure supply or old land surface.
C781	J. Stanning	2,080	538	525	448	4,626	5,074	Not known.
C795	J. Stanning	2,200	532	510	456	4,633	5,089	Not known.
C943	J. Stanning	2,080	537	509	457	4,632	5,089	Old land surface separating flows.
C981	J. Stanning	850	555	525	505	4,640	5,145	

KAMASIA

C711	Native Reserve	1,200	464	195, 380, 455	155	5,395	5,550	Water laid sediments—volcanic grits. High CO ₂ content. F=0.9 p.p.m.
------	----------------	-------	-----	---------------	-----	-------	-------	---

No.	Owner	Tested Yield in Gal./ hr.	Depth	Water Struck	REST LEVEL		Altitude	Nature of Aquifer and Remarks
					Below Surface	Reduced Level		
C59	Oldobeye (now Bock) Chamberlain.	1,400	460	?	340	5,802	6,142	Lake sediments.
C79	Oldobeye (now Bock) Chamberlain.	1,500	388	343	321	5,806	6,127	Lake sediments.
C261	W. W. Cresswell	1,400	500	270	236	6,814	7,050	Not known. No samples.
C266	A. and L. Block	1,375	500	465	348	5,819	6,167	In lake sediments above trachytic lava.
C429	Delamere Estates (Soysambu)	1,725	336	258	235	5,830	6,065	Lake sediments above phonolitic trachyte lava.
C431	A. and L. Block	1,000	720	660, 690	530	5,817	6,347	Not known, no samples. Water hot and saline.
C456	E. Pardoe (now Gamble)	400	190	163	158	5,962	6,120	Lake sediments.
C533	A. and L. Block	1,040	725	675, 716	675	5,822	6,497	Fissure supply in trachytic lava. Water cold and saline.
C785	H. M. Harries	2,000	650	435, 600	414	6,762	7,176	1st sediments intercalated in tuffs. 2nd sediments—water laid. Water hot.
C845	M. Robinson	1,167	725	445, 682, 715	420	5,800	6,220	Lake sediments.
C953	H. M. Harries	1,617	470	425, 460	310	—	—	Not known.
C1027	Lady Claud Hamilton (Nderit)	1,800	350	270	260	3,790	6,050	Old land surface and thin water laid sediment horizon separating phonolitic trachyte from porphyritic basalt.
C1145	Delamere Estates (Soysambu)	1,620	515	309, 462, 498, 515	249	5,816	6,065	Old land surface.
C1250	Greenstedts School	1,460	555	495	490	5,800	6,290	Not known. No samples.
C1287	Delamere Estates (Soysambu)	2,292	337	180	164	5,809	5,973	Lake sediments.
C1383	R. Ballantyne (Congreve Estate)	1,200	320	180, 270, 320	180	5,798	5,978	1st, lake sediments. 2nd, lake sediments above phonolitic trachyte. 3rd, fissure (?) in phonolitic trachyte. F=27.5 p.p.m.
C1395	J. Bock (Oldobeye)	1,500	606	320, 530, 550	300	5,820	6,120	Lake sediments. F=6.2 p.p.m.
C1584	Lady Claud Hamilton	2,500	283	260	58	5,799	5,857	Phonolitic trachyte lava (fissure supply ?).
C1798	A. and L. Block	1,760	622	560, 590, 622	440	5,806	6,246	Not known. Samples unreliable.
C1877	A. and L. Block	1,500	637	528, 610, 637	517	4,849	6,366	Lake sediments—water cold.
C1941	McCall and Aitkenhead	1,167	567	560	465	5,835	6,300	Fissure in phonolitic trachyte.
C1990	Delamere Estates (Soysambu)	1,667	340	270	206	5,834	6,040	Water cold and saline.
C2007	Delamere Estates (Soysambu)	1,800	355	346	323	5,820	6,143	Fissure in porphyritic basalt. Water warm. F=35.5.
C2059	M. S. Eliot (Congreve Estate)	750	388	?	67	5,943	6,010	No samples.
C2118	Delamere Estates	600	696	675	496	—	—	Drilled subsequently to original report.
C2234	Mrs. G. Gamble	2,000	543	291, 462, 488	258	—	—	Drilled subsequently to original report.
C2288	Cresswell Ltd.	Nil	910	—	—	—	—	Drilled subsequently to original report.
C2289	C. A. Filmer	1,600	464	320, 380, 440	290	—	—	Drilled subsequently to original report.
C2480	C. A. Filmer	1,500	235	115	130	—	—	Drilled subsequently to original report.
C2499	Delamere Estates	1,100	700	394, 570, 600-700	348	—	—	Drilled subsequently to original report.
C2541	Block Estates Ltd.	Nil	165	—	—	—	—	Drilled subsequently to original report.
C2542	Block Estates Ltd.	Nil	200	—	—	—	—	Drilled subsequently to original report.
C2543	Block Estates Ltd.	Nil	500	—	—	—	—	Drilled subsequently to original report.

6.—NJORO—NORTH

No.	Owner	Tested Yield in Gal./hr.	Depth	Water Struck	REST LEVEL		Altitude	Nature of Aquifer and Remarks
					Below Surface	Reduced Level		
C214	Lord Egerton of Tatton	650	400	210	180	6,285	6,465	Old land surface.
C485	Nyanza Ltd.	3,000	394	275	210	—	7,000	
C1089	G. B. Farms	Nil	800	355-390	263	6,712	6,975	Sediments, reworked tuffs intercalated in impervious welded tuffs.
C1125	Soil Conservation	2,820	410	640	575	6,135	6,710	Sediments, reworked tuffs above impervious welded tuffs. F=4.1 p.p.m.
C1362	Lord Egerton of Tatton	1,000	655	352, 496	280	6,625	6,905	Sediments, reworked tuffs above impervious welded tuffs. F=1.9 p.p.m.
C1491	W. J. Dawson	2,300	532	400, 640	318	—	—	Sediments, reworked tuffs above impervious welded trachytic tuffs.
C1934	Plant Breeding Station	570	650	420	400	6,670	7,070	
C1935	Plant Breeding Station	1,500	604					

time as the volcanic rocks referred to above. They are often scoriaceous and fissile. Nepheline has never been identified in thin sections of these lavas. There is a considerable resemblance to the faulted Nakuru phonolitic trachytes which cover the floor of the Rift Valley south of Nakuru.

Samples from boreholes C1837 and C2006 show that a succession of flows of phonolitic trachyte which underlie the Menengai volcanics on the south-west edge of the Rongai plain to the west of the volcano are underlain by flows of aphanitic phonolite with abundant interstitial nepheline. The paucity of surface exposures make it an impossibility to determine what the relationships of these lavas are to the remainder of the faulted lavas in the area.

CHAPTER V—THE MENENGAI VOLCANO

The Menengai volcanics differ from the older volcanic rocks in that they can be related to a single central volcano, Menengai, which lies immediately north of Lake Nakuru. Menengai is the largest volcanic caldera in Kenya, the crater, roughly trapezoidal in shape, covering more than 35 square miles and having an E.N.E.-W.N.W. long axis of six to seven miles. It is a subsidence caldera, complicated by renewed eruptions of lava, almost entirely confined within the caldera.

Physical Features

Menengai has a gently rounded outer profile, smooth grassy slopes rising at first steeply from the surrounding country, but easing off to a very gentle slope near the crater rim. This type of profile, contrasting as it does with the steepening profile of most volcanic cones, is in itself suggestive that the central section has been dropped by subsidence. The caldera walls are formed of abrupt cliffs, exposing tiers of successive lava flows. The height of the walls is very variable in different sections of the periphery of the caldera. In the north-west section the wall is completely absent, while on the south side it is over 1,000 feet high.

The crater is almost completely waterless; only one permanent stream, the Crater Stream, flows into it, to vanish underground on encountering the fissured and broken flows of lava covering the floor. A few damp patches occur between the bounding wall and the terminal cliffs of recent flows that have been arrested by contact with the wall. These are due to small accumulations of surface water in the hollows so formed. The fauna in the crater is very limited, the only permanent inhabitants being small antelopes and hyraxes. Though reputedly inhabited by numerous snakes, not one was seen within the crater by the writer.

Geological History of the Volcano

The First Phase

Eruption commenced with the effusion of lava from a vent situated approximately in the centre of the present caldera. Of this vent no vestige now remains. The lava was extruded over a considerable period with intermittent pauses in activity, represented by brick-red coloured old land surface deposits exposed in the wall of the caldera. The nature of the eruption was at first quiet, pyroclastic material being completely absent from lower flows exposed in the walls. The process is envisaged as a welling out of lava from the vent; the flows extending further and further from the vent as the volcano built itself up above the surrounding country. The uppermost flow of the series extends to a distance of more than six miles from the centre of the caldera, whilst the lower flows appear to have terminated much nearer the vent.

The earliest flows are composed of porphyritic trachyte with a spherulitic micro-texture. The spherulitic clusters of feldspars are commonly interspersed with small cavities, devoid of any secondary infilling. These lavas are normally black in colour, but a brown coloration is seen in the vicinity of old land surfaces separating the flows. Subsequently more glassy lava was poured out and the topmost flow exposed in the wall consists of grey trachytic glass, passing up into green devitrified and scoriaceous

glass. This uppermost flow has the appearance of a single lava flow but shows a streaky banding and inclusions of pyroclastic material, and there is one well-marked horizon containing boulders of trachytic lava in a devitrified glassy matrix; the boulders are angular and some exceed four feet in diameter. The uppermost flow is thought to be a welded tuff or trachyte ignimbrite. The uppermost horizon of all consists of green crystal trachytic tuff composed of clear felspar crystals and small pyroclastic fragments in a glassy matrix. This tuff is known locally as "building stone". It varies considerably in appearance and texture, forming discontinuous outcrops on the outer slopes. On the south and east slopes coarse dominantly crystal tuffs outcrop, while on the northern slopes finer green glassy ash overlies the uppermost ignimbrites.

In March, 1957, workings in a quarry on the Eldama Ravine road, one mile west of Nakuru, exposed moulds of trees, within the body of the uppermost ignimbrite flow of Menengai. These moulds (Plate 1) have the form of cylinders, of a foot diameter and about six feet in height. They taper upwards. Only two vertically situated moulds were seen, but there were many more in the floor of the quarry, lying horizontally with a parallel arrangement away from the centre of Menengai. Some of these horizontal moulds are very small (branches?) and a bifurcation suggesting the branching of a tree was seen in one case. The vertical cylinders show a crude spiral ribbing pattern. The ignimbrite is discoloured and oxidised, where in contact with the moulds, which contain a little loose gravel but no charcoal. The banding of the ignimbrite is bent upwards around the tree moulds. The absence of any charcoal is explained by the theory that the trees were completely vaporized by the enveloping mass of incandescent ash and gas, which rolled down the mountain side in a heavy cloud or *nuée ardente*. The cloud coalesced into a mass of very hot glass which subsequently moved a little way down the slope, in the manner of a lava flow, thus producing flow structures. It is noteworthy that the trees are situated near the termination of the flow where coalescing would be advanced and movement sluggish. The preservation of these tree moulds *in situ* is strong evidence for an origin in *nuées ardentes* for these welded tuffs; a normal trachyte lava near its termination would almost certainly uproot the trees and would leave some remnant in the form of charcoal.

Within the coarse glassy tuffs on the eastern slopes are included small fragments of aegirine syenite, a coarse holo-crystalline rock thought to be derived from a central intrusive plug of syenite underlying the original vent. This may be compared with the well-known syenite plugs of Mount Kenya and Mawenzi. Many boulders of this syenite are scattered on the slopes of the volcano above Menengai Farm. This syenite is completely devoid of nepheline, compatible with the fact that nepheline has not been identified in any of the Menengai lavas. It is probable that syenite represents the hyperbyssal magma from which the trachyte effusives were derived. Similar syenite boulders are found on Longonot (verbal communication, Mr. R. G. Dodson).

The condition of the volcano at the termination of the first phase of eruption is envisaged as a cone, with a diameter of about 12 miles; the slopes were smooth, rising to a comparatively small central crater between 8,000 and 9,000 feet above sea level.

The Formation of the Caldera

Calderas are defined as "extensive craters out of all proportion to the size of the volcano". Two mechanisms are generally accepted for their formation: (i) catastrophic evisceration by explosion; (ii) piecemeal foundering of the superstructure of the cone into the underlying magma chamber. The fundamental difference between the two processes is that in the first type of caldera the material from the obliterated superstructure is scattered in the form of pyroclastic deposits over a large area, outside the limits of the caldera, whilst in the second process the bulk of the lost material is engulfed within the limits of the caldera. A caldera that shows extensive evidence of inward foundering is considered to be a subsidence caldera even though explosive eruptions played a large part in its formation. Subsidence calderas are characterized

by large deposits of airborne pumice around the volcano, but little or no fragments recognizable as being derived from the original superstructure. Menengai is a caldera showing such features. Subsidence was undoubtedly the dominant mechanism, though this subsidence appears to have been the direct result of explosive eruptions.

The sequence of events in the formation of subsidence caldera is illustrated in Fig. 2 which is based on the work of van Bemmelen and Howell Williams and appears in *Physical Geology* by A. Holmes, 1944. The magma chamber underlying the central vent is supposed to be stoped out until it has a much greater diameter than the vent; the level of the magma can be dropped, either as a result of explosive eruptions rapidly ejecting a large part of it through the central vent, or through the opening of a parasitic vent on the lower slopes of the volcano, tapping the central magma reservoir. The sudden, recession of the magma level leaves the superstructure of the cone wholly unsupported, fractures develop, and blocks of the superstructure founder into the depths, where they are probably to a certain degree assimilated. There is no evidence of any parasitic vent near Menengai, and there is evidence that the formation of the caldera coincided with a period of explosive eruption scattering pyroclastic material over a wide area surrounding the volcano.

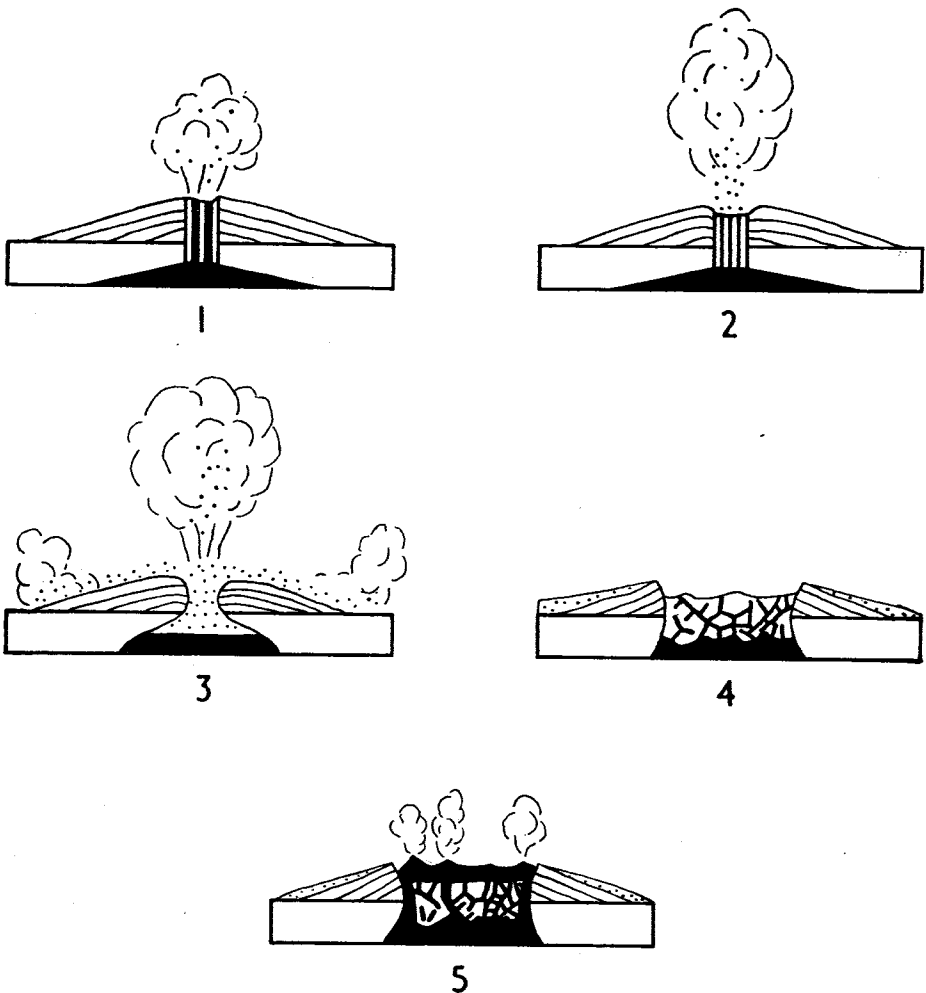


Fig. 2.—Subsidence calderas. The mechanism of formation. (After A. Holmes, van Bemmelen and H. Williams.)

This evidence of explosive eruptions, initiating the foundering process is seen in the increased pyroclastic content, and the highly scoracious nature of the ignimbrite that forms the uppermost layer of the original volcano. This ignimbrite is sharply truncated by the present-day bounding fractures that circumscribe the caldera, but it is probably contemporaneous with the actual explosions that started the subsidence. It is indeed possible that sections of the cone nearer to the vent had already commenced to founder simultaneously with the eruption of these lavas and pyroclasts, but the major part of the caldera formation post-dated the deposition of these ignimbrites.

In the surrounding country the explosive eruptions which initiated the caldera are thought to be represented by the extensive deposits of tuff and ash which overlie the older-faulted lavas. For example at:—

Makalia	..	..	..	Makalia Ash.
Njoro	..	..	..	} Black Ash.
Rongai	..	..	..	
Elburgon	..	..	..	
Solai	..	..	..	Solai Tuff.
Mbaruk	..	..	..	Building Stone.

These deposits vary greatly in colour and texture but all are trachyte tuffs, with abundant felspar crystal fragments. They can easily be cut into rectangular blocks for building purposes. All these formations outcrop in the bottoms of the present-day valleys, possibly having been washed in by rainwater. They are thus of subsequent age to the formation of the present drainage pattern. These tuffs often contain rounded fragments of green pumice, and of black obsidian with prominent felspar insets, a rather unusual lava type also observed in the highest glassy trachyte flow of Menengai caldera wall. These tuffs are affected by minor faults believed to be coincident with the subsidence movements which formed the caldera. In a subsequent section dealing with the sedimentary formations it will be seen that there is evidence that these tuffs are about 10,000 years old. It is likely, therefore, that the caldera of Menengai was formed somewhat less than 10,000 years ago.

That subsidence has taken place cannot seriously be doubted. Subsidence structures are preserved at several points along the rim. These structures are characterized by a reversal of the normal outward dip of the lava flows in the wall, a marked tilt inwards having been effected. Where only partially developed the structures are monoclinical, but the more strongly developed structures are bounded by steep or vertical fault dislocations. For example, on the south wall, between the Menengai Forest Reserve and the caldera, a block of the wall is preserved in a partially foundered state. This block is bounded on either side by monoclinical flexures, but these pass into a fault dislocation in the centre section, duplicating the caldera wall over a distance of about a mile. The tongue-like projection of the wall on the western margin shows all the features typical of these structures. The outward slope of the lavas in the wall is reversed by a gentle monoclinical flexure which passes inwards into several abrupt dislocations having very steeply towards the crater, and throwing down the peninsular segment of the wall 300 feet into the crater. This is illustrated in Figs. 3 and 4, drawn from photographs, which clearly show the marked tilt of the subsided block towards the centre of the crater.

Subsidence in the north-west sector has dropped the rim of the crater to such an extent that later lava flows erupted within the crater have piled up higher than the actual rim, and the terminal cliff of the later lava flow rises 100 feet above the rim, the caldera wall being completely obscured by this later flow. This structure and the two trough-like structures near Rhodora Farm and Prentice's Farm appear to have developed along earlier structural lines disrupting the underlying faulted lavas over which the volcano erupted. In the Rhodora structure a central flap, bounded

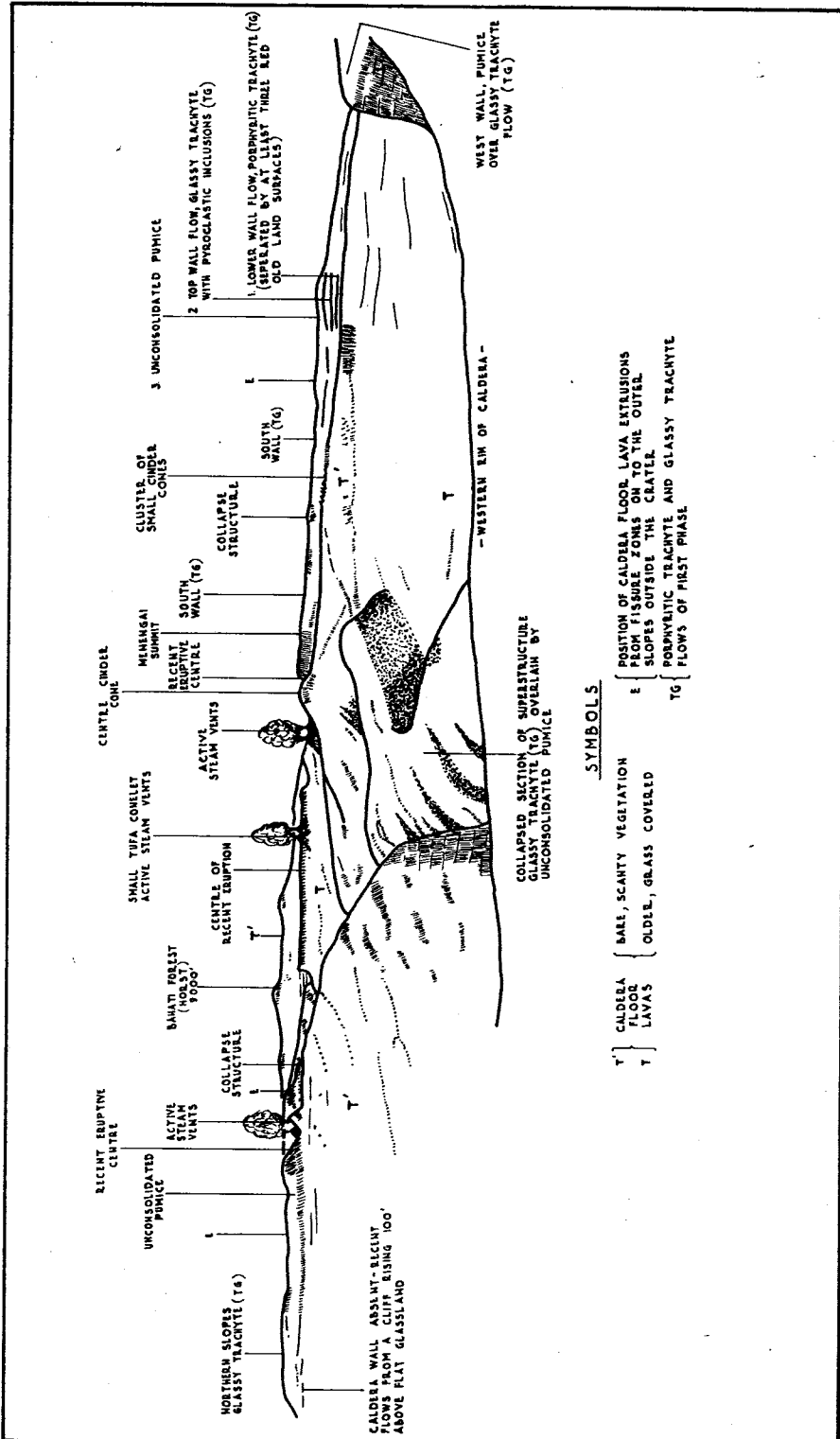


Fig. 3.—Menengai Crater. View from the western rim.

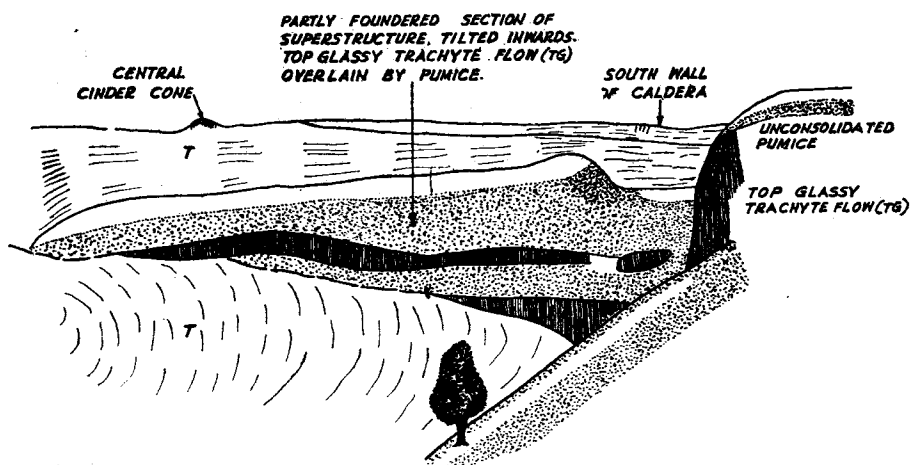


Fig. 4a.—Sketch of subsidence structure on western side of caldera.

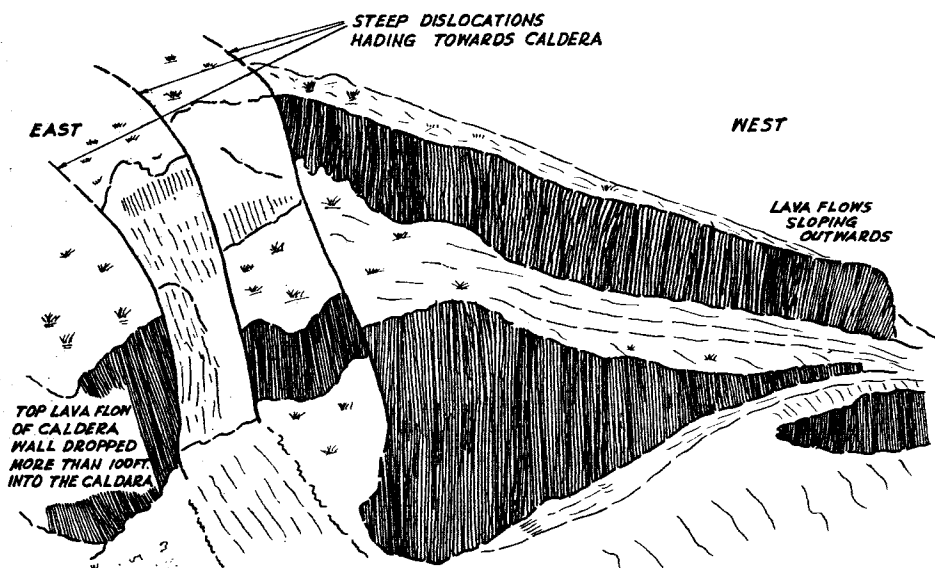


Fig. 4b.—Sketch showing the reversal of the normal outward slope of lava flows in a promontory projecting from the western wall of Menengai caldera, consequent on the foundering of the central part of the volcano.

(Erratum: for top lava read trachyte ignimbrite.)

by faults has dropped inwards along a hinge-like monoclinical flexure, parallel to the caldera wall. The curved facets in the crater rim are revealed most strikingly on the map (Map No. 3) and are in themselves a strong indication of the piecemeal nature of the subsidence process.

Secondary Eruptions Contemporary and Subsequent to the Caldera Formation

Though these secondary eruptions are certainly to some extent later in date than the Elmenteita Basalt eruptions they are for convenience described here together with the earlier Menengai volcano eruptions.